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WATER AND RELATED LAND RESOURCES MANAGEMENT STUDY. VOLUME V. SU--ETC(U)
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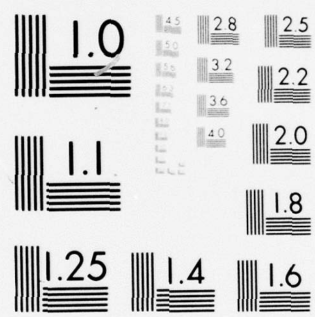

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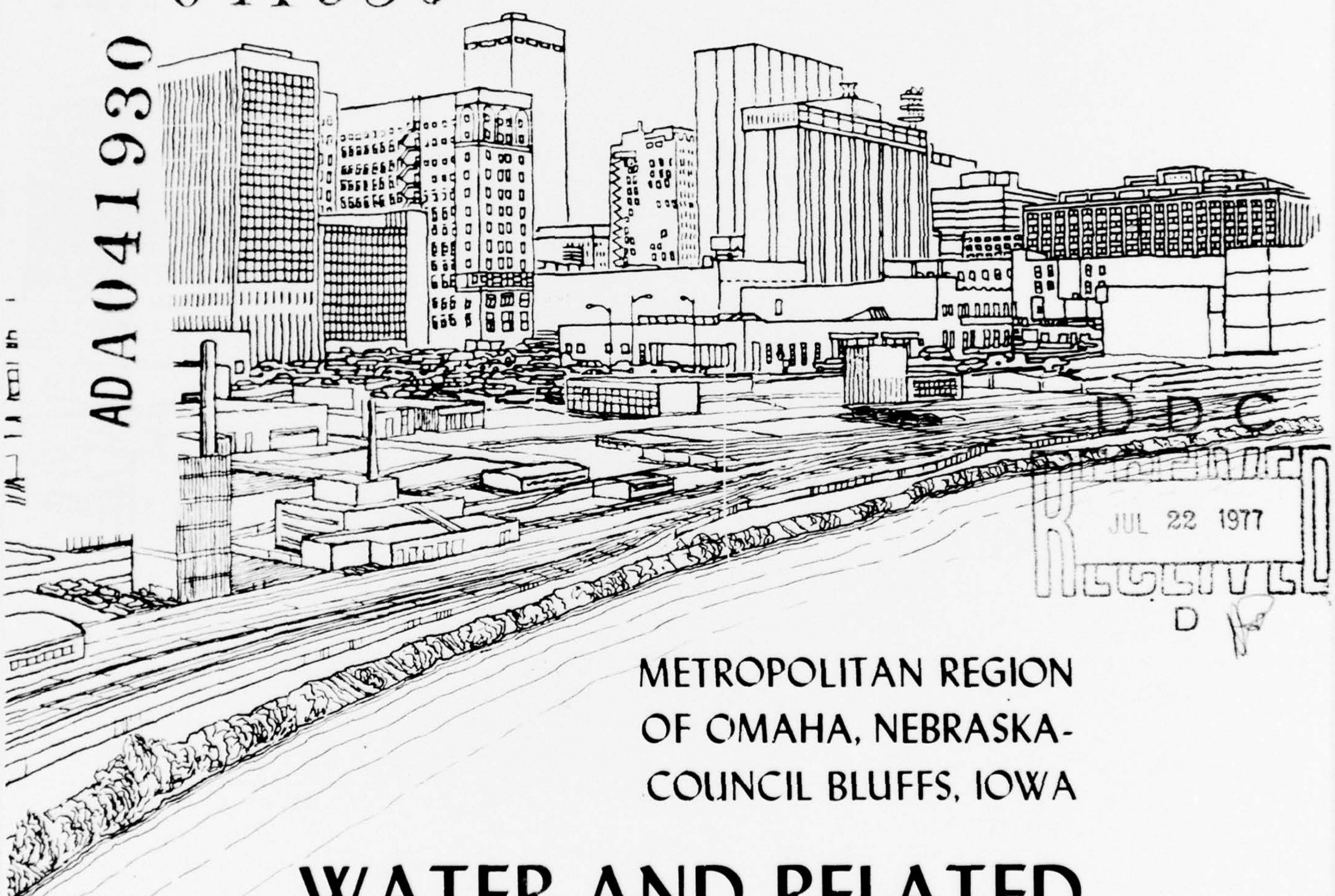
VOLUME V
SUPPORTING TECHNICAL REPORTS APPENDIX

ANNEX D - URBAN STREET POLLUTANT ANALYSIS

REVIEW REPORT ON THE MISSOURI RIVER AND TRIBUTARIES



METROPOLITAN REGION
OF OMAHA, NEBRASKA-
COUNCIL BLUFFS, IOWA

WATER AND RELATED LAND RESOURCES MANAGEMENT STUDY

JUNE 1975

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URBAN STREET POLLUTANT ANALYSIS

6 Water and Related Land Resources Management Study.
Volume V. Supporting Technical Reports Appendix.
Annex D. Urban Street Pollutant Analysis.

11 Jun 75

12 35p.

Omaha District, Corps of Engineers

Special Investigation Report

for the

Metropolitan Omaha, Nebraska-Council Bluffs, Iowa Study

June 1975

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FROM STREET SWEEPING PROGRAM

SECTION I

SUMMARY
DOCUMENTATION OF FINDINGS AND CONCLUSIONS
FROM STREET SWEEPING PROGRAM

1.1. Summary.

The Corps of Engineers participated in a cooperative sampling program with the City of Omaha during the summer of 1974, to measure the accumulation and runoff pollution potential of street debris. In total, eight (8) residential sectors and two (2) commercial sectors were swept with mechanical street sweepers on a rotating, sequential basis. The approximate sweeping frequency for each sector was once every two (2) weeks. The total debris collected by the sweeper was determined by weighing; the size distribution of the debris was determined by dry sieving samples in the laboratory.

Concurrent with the street sweeping program, hand sweeping samples were collected from the same residential sectors to evaluate the potential runoff pollution impact of the debris. Laboratory analyses of these samples included a dry sieve analysis to determine the size distribution of both the organic and inorganic fractions of the debris and measurement of several quality parameters. Quality measurements were made on only the suspended and suspended plus settleable fractions of the debris. The quality parameters measured in the laboratory were chemical oxygen demand, 5-day biochemical oxygen demand, extractable phosphate, kjeldahl nitrogen, and heavy metals consisting of lead, mercury, zinc, chromium, and nickel. A total coliform count was also

determined. Hand sweeping samples were not collected in the commercial sectors because both are heavy traffic areas and extensive measures would have been required to insure the safety of sampling personnel.

The major purpose of this study initially was to acquire factual field data to input into the water quality subroutine of the Storage, Treatment, Overflow, and Runoff Model (STORM). The water quality subroutine of this model was developed with the contention that essentially all urban pollution originates from streets. This model was to be applied in latter phases of the Metropolitan Omaha, Nebraska-Council Bluffs, Iowa Study to:

1. Verify levels or substantiate changes in assumed urban runoff pollution loadings;

2. Define variances in expected urban runoff pollution levels;

3. Define variances in pollution levels between urban sectors; and

4. Define optional design requirements for collection, storage, and treatment of urban runoff.

However, based on the results of the data collection program and subsequent analyses, it was determined fairly conclusively that most urban runoff pollution probably does not originate from debris in the streets at the time of a rainfall event. Study efforts were then modified to 1) fully describe and substantiate this conclusion; (2) identify and quantify other sources of urban runoff pollution; (3) evaluate some non-structural methods of reducing urban runoff quantity and pollution

loading; (4) evaluate and recommend changes in STORM and (5) discuss additional data and study needs to develop a more complete understanding of the urban runoff pollution process. Some portions of the analyses in this report include extrapolation of measured data and data synthesis. All such data developments were supported by other research studies published in the literature. The major findings of this study are briefly summarized in the following sub-paragraphs.

a. The quantity of debris found on residential streets within Omaha during the study period ranged from 65 to 1660 pounds per curb mile of street. The quantity of debris on the street appeared to be highly correlated to the age of the residential development. For this reason, the residential data analysis was sub-divided into two groups - "old" residential developments and "new" residential developments. Four study sectors were included in each grouping. The average accumulation of debris on the streets for the "old" and "new" residential groupings was 765 and 150 pounds per curb mile, respectively.

b. The particle size distribution of the inorganic fraction of the street debris was found to be essentially log normal with a mean particle size of approximately 0.5 mm. The organic debris had a mean particle size of 2.2 mm. Only 11 percent of the total debris was finer than sand and only 0.5 percent was clay size.

c. Only a portion of the total debris on the street is of a size fraction that can be removed from the street by precipitation and transported in suspension by runoff through a drainage system. An

even smaller fraction of the total debris remains suspended in water during storage. Laboratory procedures were devised for this study to simulate the potential pollution level of the street debris for each of these states. The measured pollution load for the latter case was defined as the suspended load. The difference between the simulated runoff pollution load and the suspended load was defined as the settleable pollution load. Findings from other studies were used to estimate the total pollution load of the street debris. The comparative pollution loadings for the average residential street debris loading were determined to be as follows for the major parameters:

AVERAGE SUSPENDED, SETTLEABLE, AND TOTAL POLLUTION LOAD FOR STREET DEBRIS IN OMAHA, NEBRASKA IN POUNDS PER CURB MILE OF STREET

Pollutant Parameter	Suspended Load	Settleable Load	Total Load
Total Solids	3.8	61.4	456.5
Vol. Solids	1.5	8.3	84
BOD_5	1.2	2.5	10.5
COD	1.9	10.2	24.6
Kjel. Nit.	0.065	0.18	0.74
Ext. PO_4	0.05	0.19	0.35

Source: Tables 5 and 7

d. Street sweeper efficiency was estimated from a comparison of the quantity of debris collected by the street sweepers to the quantity of debris collected by hand sweeping. The resultant efficiencies were 33 and 59 percent for the grouped residential classification of "old"

and "new", respectively. Lower sweeper efficiencies in the "old" sectors were probably attributable to considerably greater on-street parking during sweeping and poorer general repair of the streets.

e. The accumulation rate for street debris was not linear, as generally assumed, through the two and one-half month study period. Several averaging techniques were used to linearize the data for subsequent computations with STORM. The determined accumulation rates for the grouped residential study sectors were 1.46 and 0.29 pounds per day per 100 curbic feet for "old" and "new" residential groupings, respectively.

f. Average annual runoff pollution loads were computed by STORM using the street debris data collected in this study. A 25-year (1949 through 1973) evaluation period was used in this analysis. The average annual pounds of pollution removed by runoff was determined to be 84 pounds of total solids and 5.6 pounds of BOD_5 per acre. A street density of 300 curb feet per acre was used in this evaluation. The average pollutant concentration in the runoff assuming a 30 percent impervious land area was 56 and 3.8 mg/l for total solids and BOD_5, respectively. These concentrations are only about 20 percent of the average concentrations generally assumed for urban runoff. Similar results were obtained using street debris data from other studies. It was concluded, based on these findings, that streets are probably not the major source of urban runoff pollution. The principal reason as postulated by this study is that street debris is comprised of only

a very small percentage of silt, clay and finer-sized particles. It is this fine and very fine debris fraction that has the most significant impact on water quality both from the standpoint of ease of water transport and also the associated pollutant concentration.

g. It is speculated, based on synthesized data, that dustfall on impervious surfaces other than streets may be the major source of measured urban runoff pollution. The Omaha-Douglas County Health Department measured dustfall rates in the City of Omaha during the period of October 1965 through March 1968. This study found that the average annual dustfall rate for their sampling sites within Omaha were approximately 80 and 220 tons per square mile of soluble and insoluble particulates, respectively. The insoluble particulates are generally finer than 40 microns in diameter. Based on estimations of the pollution "strength" of this fallout, more than 200 pounds of total solids and 22 pounds of BOD_5 per acre of urban land use were determined to be removed annually by precipitation from the impervious surfaces other than streets. This analysis is based on an assumed total imperviousness of 30 percent and an average street length of 150 linear feet per acre. These values are several times greater than the average annual computed 84 and 5.6 pounds of total solids and BOD_5, respectively, determined to be removed from the street. Additional research studies will be needed to support or disclaim the importance of dustfall in urban pollution.

h. Streets may serve a greater role in the total urban runoff pollution cycle than merely the contribution of pollution during a runoff event. Streets are possibly the initial source of pollutional debris removed from other areas during runoff. The two most notable cases are 1) fine dust blown off of the street onto the surrounding land surfaces during dry periods, and 2) organic and other debris deposited in catch basins during preceding precipitation events or by traffic.

i. The accumulation of debris on streets is significantly greater in older residential land use areas than in the newer residential land use areas. Several physical factors probably explain this finding. The major causal factors identified by observations in this study are 1) the amount of vegetative canopy covering the street, 2) the amount of on-street parking, 3) the general repair of the street, 4) the socio-economic level of the area, and 5) the amount of traffic. Quantification of the role of each factor was beyond the scope of this study.

j. An optimization analysis determined that the most effective street sweeping frequency for Omaha in reducing the portion of runoff pollution originating from the street was approximately 11 to 16 days. The evaluation was completed using the time continuous computational element of STORM for the historic hourly precipitation record at Epply Airfield for years 1949 through 1973. The total reduction in street runoff pollution, assuming a 50 percent efficient street sweeper, would be about 30 to 40 percent.

k. A long-term analysis of precipitation intensity for Omaha indicates that drainage of impervious runoff across pervious lands could significantly reduce the average quantity of runoff from an urban area. At the same time, some reduction in runoff pollution would also be experienced. The computed reduction in impervious runoff was about 73 percent for drainage of an impervious area uniformly across an equal area of pervious land. The degree of reduction decreases with increasing precipitation intensity, and probably decreases to about zero for any major "design" storm event.

l. The findings of this study indicate rather conclusively that considerable research effort is still needed to define the sources of urban runoff pollution. Present modeling attempts which use street debris as the major pollutant source are considered inadequate. Further development and employment of these models should be conceived around a more thorough understanding of this runoff pollution process. To support this development, additional research is needed to 1) identify and quantify the major sources of urban runoff pollutants, 2) describe the accumulation-removal processes for pollutants at each source, and 3) describe any interactive relationships between sources, e.g., streets being a source of dust collecting on other areas.

SECTION II

INTRODUCTION

SECTION II - INTRODUCTION

2.1. Purpose and Scope.

The purpose of this report is to document the results of engineering investigations to identify and characterize urban runoff pollutants and to evaluate the adequacy of an existing water quality management model. This study was conducted to define the expected quality of urban runoff from the Omaha, Nebraska-Council Bluffs, Iowa Metropolitan Study area. Two computer simulation models have recently been developed to aid both planning and design engineers in defining and abating the urban runoff quality problem. These two models are the Environmental Protection Agency's Storm Water Management Model (SWMM) and the Corps of Engineers' Storage, Treatment, Overflow and Runoff Model (STORM). The SWMM is a sophisticated model developed for design work applications. The STORM, however, was developed as a management model. The simplicity of this model enables the engineer to evaluate the effectiveness of alternative designs using the historic precipitation record. This model has been recommended by OCE for use in the urban study programs of the Corps of Engineers. Both models use a similar water quality subroutine but the logic and completeness of these routines have not been verified because of insufficient data.

A sampling program was established within the City of Omaha during the summer of 1974, to characterize and quantify street debris. It is the developmental contention of STORM that streets are the single major source of urban pollutants during runoff. The collected

data is used to test the validity of this logic element in the model. An evaluation of the mass emission of pollutants during runoff from other identifiable sources was completed using literature values and other data sources.

The results of these analyses are used to evaluate the effectiveness of potential nonstructural measures for improving urban runoff quality and to evaluate and recommend modifications to the water quality subroutine in STORM.

2.2. State of the Art.

Until recently waste water management studies have been limited to a large degree by an inability to assess the expected impact from urban runoff. In general, simplification for expediency has usually reduced runoff quality considerations to the use of an "average" concentration for each constituent. An average value oversimplifies a highly variable parameter. Researchers have attempted to correlate measured runoff quality to various hydrologic factors such as intensity and duration of runoff. These attempts have not generally been successful (8). Probably the major reason is that the available pollutants in the watershed vary with time.

Recent approaches to predicting and quantifying urban runoff quality are attempting to define the "in situ" pollution sources and simulate the accumulation and washoff of the pollutants from these sources. There are essentially only two major sources of pollutants from separated sewer urban areas - catch basins and the land surface (8). The major source is the dust and debris that collects on the

land surface. This approach is considered to be the present state-of-the-art technique (8,9). The two computer models mentioned previously (SWMM and STORM) have subroutines which are intended to simulate the washoff of the dust and debris during a rainfall event. Since STORM has potentially greater application for management studies, the existing applicability of the water quality subroutine was tested for possible applications in the Metropolitan Omaha, Nebraska-Council Bluffs, Iowa Urban Study. The major components and required input data for STORM is summarized in the next unit.

2.3. Storage, Treatment, Overflow and Runoff Model (STORM).

a. General. Current objectives and applicable methodologies for urban stormwater runoff management studies have been outlined in ETL 1110-2-515, 28 February 1974. This letter states that:

> "STORM provides acceptable procedures for survey scope studies to aid in the selection of the stormwater storage and rates of treatment required to achieve a desired quantity and quality of discharge to the receiving waters."

The model consists basically of five (5) computational elements or subroutines. These major elements are: 1) computing snowmelt runoff, 2) computing rainfall runoff, 3) computing runoff quality, 4) computing treatment, storage, and overflow, and 5) computing land surface erosion. Subroutines 2, 3, and 4 will be discussed briefly in the following subsections. A thorough discussion of model operation is available in the listed references (9, 10). The major data inputs to the model include:

1. Number and size of watersheds to be considered.
2. Hourly historic precipitation record.
3. Average or max/min daily air temperature (optional).
4. Monthly evaporation rate in inches/day.
5. Runoff coefficient for pervious and impervious areas.
6. Average depression storage for the urban area.
7. Number, type, and description of urban land use groups (limited to single family, multifamily, commercial, industrial, and open or parkland categories).
8. Rate of dust and dirt accumulation for each land use group.
9. Pounds of each pollutant per 100 pounds of dust and dirt for each land use group (limited to suspended and settleable solids, biochemical oxygen demand, total nitrogen and phosphate).
10. Frequency and efficiency of street sweeping.
11. Non-urban area in watershed.
12. Values for 5, 6, 8 and 9 above for non-urban area.
13. Input values for SCS "soil loss equation" (optional).
14. Number and size of storage-treatment combinations to be considered.

The major program outputs include:

1. Date, hour, and quantity of runoff going into storage, treatment, and overflow for each precipitation event.*

*An event is defined in the program as sufficient precipitation runoff to require storage to be used, or if zero storage and treatment is specified, anytime runoff occurs.

2. Summary table listing average annual number of events, precipitation, runoff and overflow.

3. Storage utilization curve.

4. Pounds of each pollutant "washoff" during each precipitation event.

5. Summary table listing average annual pounds of each pollutant removed from the watershed, fraction overflowing to receiving water, and average concentration of each pollutant.

6. Selected event pollutograph.

b. Computation of the Quantity of Runoff. The hourly precipitation input data is converted directly to runoff in the model by the equation:

$$R = C_c(P-F) \qquad (1)$$

where

R = Urban runoff in inches per hour.

C_c = Composite runoff coefficient dependent on urban land use.

P = Precipitation in inches per hour

F = Available depression storage in inches per hour.

The composite runoff coefficient, C_c, is determined in the model by fractionally combining C input values for pervious and impervious areas based on areal percentage of each. The use of the available depression storage function, F, makes the equation dynamic. The value of this function is computed continuously by the following expression:

mercury, zinc, chromium, and nickel. A total coliform count was also

$$F = Fo + N_D K, \; F \leq D \qquad (2)$$

where

Fo = Available depression storage, in inches at the end of the last rainfall.

N_D = Number of dry days since previous rainfall.

K = Input value representing recovery of depression storage from evaporation in inches/day.

D = Input value for maximum available depression storage in inches.

As noted from the above equations, all computations retain the "inches of depth" to define the volumetric component. This simplifies program computations. An example of the program logic for computing runoff is shown in Figure 1.

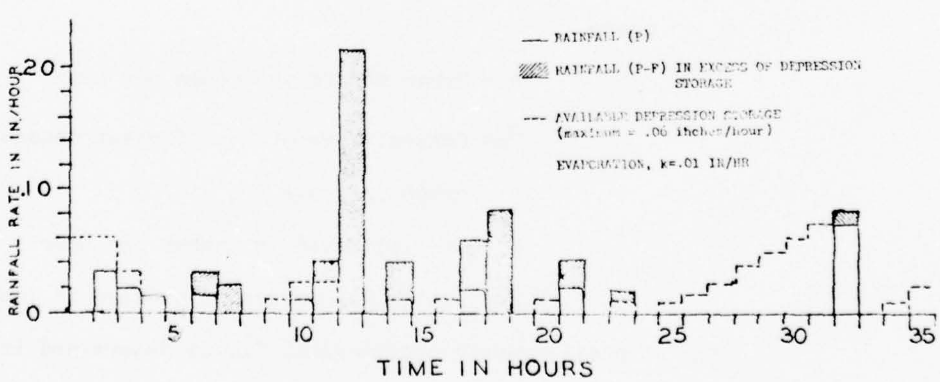


Figure 1 - Time History of Rainfall-Runoff Event

Source: Documentation Report, Computer Program 723-S8-L2520, May 1974

c. <u>Computation of Quality of Runoff.</u> The basic logic behind the quality subroutine is that:

1. The major source of pollutants in an urban area is the dust and debris that collects on the land surface and that most of the accumulated material removed by rainfall originates from the impervious surfaces (8). To simplify identification, streets are assumed to be the source of all the accumulated debris.

2. There is a definable rate at which this dust and debris accumulates on the street.

3. The pollutants originating from an urban area have some associated "strength" relative to the amount of accumulated dust and debris, and that this relationship is linear.

4. The removal, or washoff, of this material is a function of rainfall and runoff intensity.

5. The accumulation rate and the associated pollutant "strength" for a given urban area is a function only of the general type of urban land use.

Perhaps each of these logic assumptions is oversimplified and understated. However, by keeping in mind that a time history analysis is the key aspect of the model, computational elements must be kept to a minimum because of computer time. The model has not been verified because sufficient data has not been available to test simulation adequacy of the quality subroutines.

The quality subroutine in the program is comprised of several time dependent computational steps. Since this routine is utilized

extensively in this study, the developmental methodology was extracted from the STORM documentation report for inclusion here (10).

The rate of dust and dirt accumulation, DD_L, for a given land use, L, can be expressed as :

$$DD_L = dd_L \ (G_L/100) \ A_L \qquad (3)$$

where

DD_L = Rate of dust and dirt accumulation on a watershed of land use L in lbs/day.

dd_L = Rate of dust and dirt accumulation for land use L in lbs/day/100 feet of gutter.

G_L = Feet of street gutter per acre for land use L.

A_L = Area of land use L in acres.

If the number of days since the last runoff is less than the street sweeping interval, the initial quantity of a pollutant c on a watershed of land use L at the beginning of a storm is computed as:

$$P_P = F_p DD_L N_D + P_{po} \qquad (4)$$

where

P_P = Total pounds of pollutant p on urban land use L at the beginning of the storm.

F_p = Pounds of pollutant p per pound of dust and dirt.

N_D = Number of days without runoff since the last storm.

P_{po} = Total pounds of pollutant remaining on land use at the end of the last storm.

If the number of days without runoff is greater than the street sweeping interval, the following expression is used:

$$P_p = P_{po}\,(1-E)^n + N_s DD_L F_p((1-E)^{n-1}+\ldots+(1-E)) \quad (5)$$

$$+ \; DD_L F_p(N_D \;\; nNs)$$

where

N_s = Number of days between street sweepings

n = Number of times the street was swept since the last storm

E = Efficiency of the street sweeping

Finally, the expression used to compute the rate at which pollutants are washed off the watershed is

$$MU_p = P_p\,(1-e-R_I Kt)/\,t \qquad (6)$$

where

R_I = Runoff rate in inches/hour from impervious surfaces

t = One hour, the fixed time interval in STORM

K = Urban washoff decay coefficient

This equation must be modified, however, because not all of the dust and dirt on the watershed is available for inclusion in the runoff at a given time, t.

The following set of equations is used to calculate the rate of washoff, M, of the suspended solids (sus), settleable solids (set), biochemical oxygen demand (bod), total nitrogen (nit) and orthophosphate (PO_4).

$$MU_{sus}(t) = A_{sus}\,P_{sus}(t)\ \text{EXPT} \qquad (7a)$$

where

$$A_{sus} = \text{Availability of suspended material}$$

$$= 0.057 + 1.4R^{1.1}$$

$$\text{EXPT} = (1-e^{-KR_I}) \quad \text{for} \quad t = 1 \text{ hour}$$

$$MU_{set}(t) = A_{set}P_{set}(t)\ \text{EXPT} \qquad (7b)$$

where

$$A_{set} = \text{Availability of settleable material}$$

$$= 0.028 + R^{1.8}$$

$$MU_{bod}(t) = P_{bod}(t)\ \text{EXPT} + 0.10\ MU_{sus} + 0.02MU_{set} \quad (7c)$$

$$MU_{nit}(t) = P_{nit}(t)\ \text{EXPT} + 0.045\ MU_{sus} + 0.01MU_{set} \quad (7d)$$

$$MU_{PO4}(t) = P_{PO4}(5)\ \text{EXPT} + 0.0045\ MU_{sus} + 0.001MU_{set} \quad (7e)$$

d. Computation of Storage, Treatment and Overflow. Desired storage sizes and treatment rates to be evaluated by the model are specified again on the basis of the "inch" depth component. The computations proceed at an hourly step-by-step interval with the following rationale. Every hour in which runoff occurs, the treatment facility is used to treat as much runoff as possible. When the runoff rate exceeds the specified maximum treatment rate, storage is utilized to contain the runoff. When runoff again becomes less than the treatment rate, stored water enters the treatment facility at a rate equivalent to the difference between maximum treatment rate and the present runoff rate. If the storage capacity is exceeded, all excess runoff overflows into the receiving waters and becomes lost from the system. This approach

is best defined by the time history rainfall, runoff, treatment, storage, and overflow event example in Figure 2a, b and c. Figure 2a is a reprint of Figure 1. Descriptively, Figure 2 shows that the hourly excess rainfall from 2a enters the treatment facility in 2b with the excess going into storage in 2c. Storage in 2c is reduced when treatment capacity becomes available and overflow occurs when both treatment and storage capacity is exceeded. The time period for the event ends when there is no longer any water in storage or for this example, hour 28. The event starts when storage is first utilized, or hour 12.

e. Sensitivity of Quality Subroutine to Input Values. Several input values are utilized in the quality subroutine. Most of these have been defined previously. However, computed quality output values are more dependent on some input parameters than on others. A sensitivity analysis was conducted on the model using 1973 precipitation data; land use, imperviousness, street lengths, sweeper frequency, and sweeper efficiency values derived for the Cole Creek Basin in Omaha, Nebraska; and the quality "default" values included in the program. "Default" values are maintained in the program to be used if a better definition of the parameters is not available. The quality "default" values were obtained from a study in Chicago, Illinois (1). The "default" value for K was derived using equation 6 with the assumption that a rainfall intensity of 0.5 inches per hour would remove 90 percent of the debris accumulated on the streets in a one-hour period (10). These input values and the computed results were assumed as the base. Each

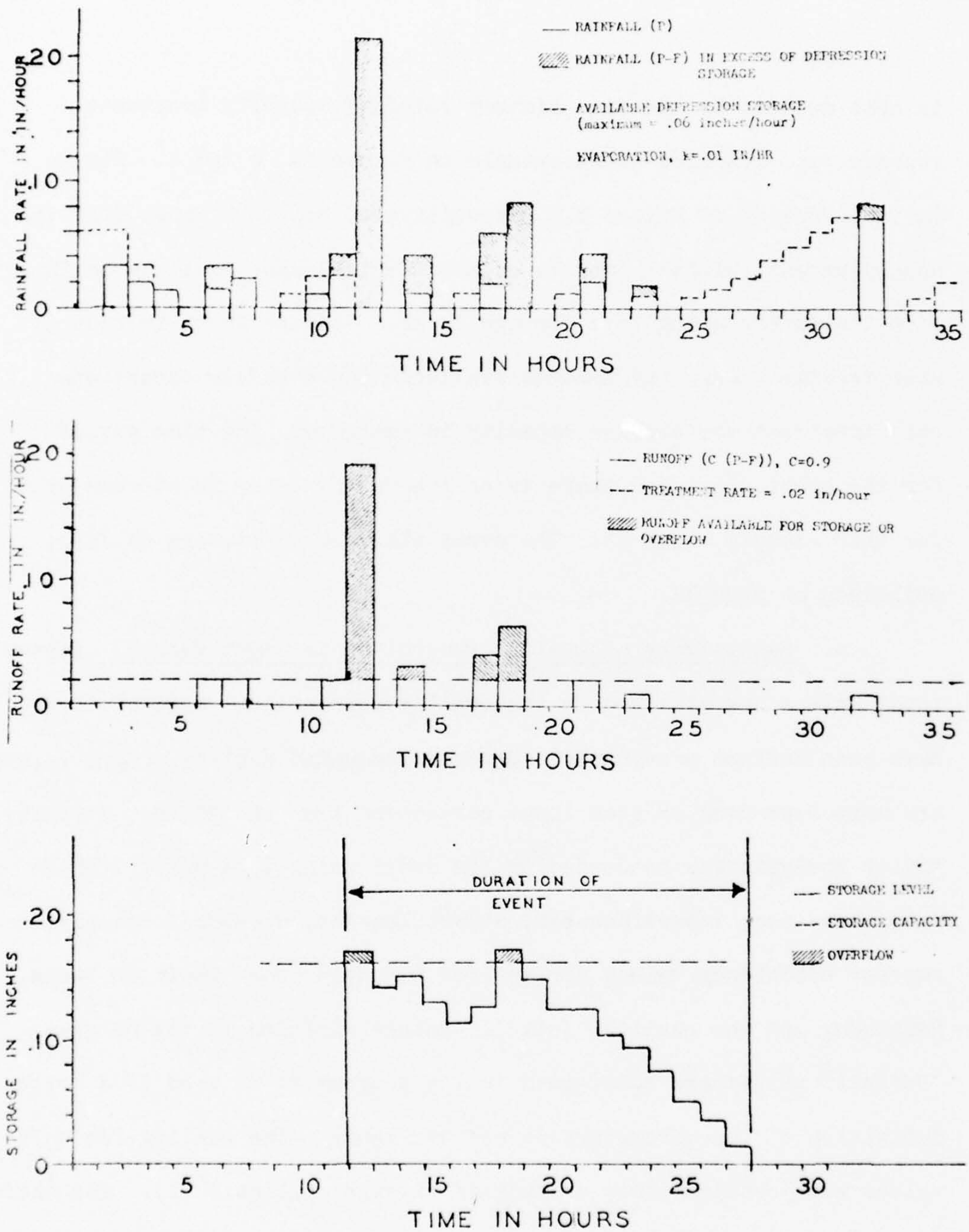


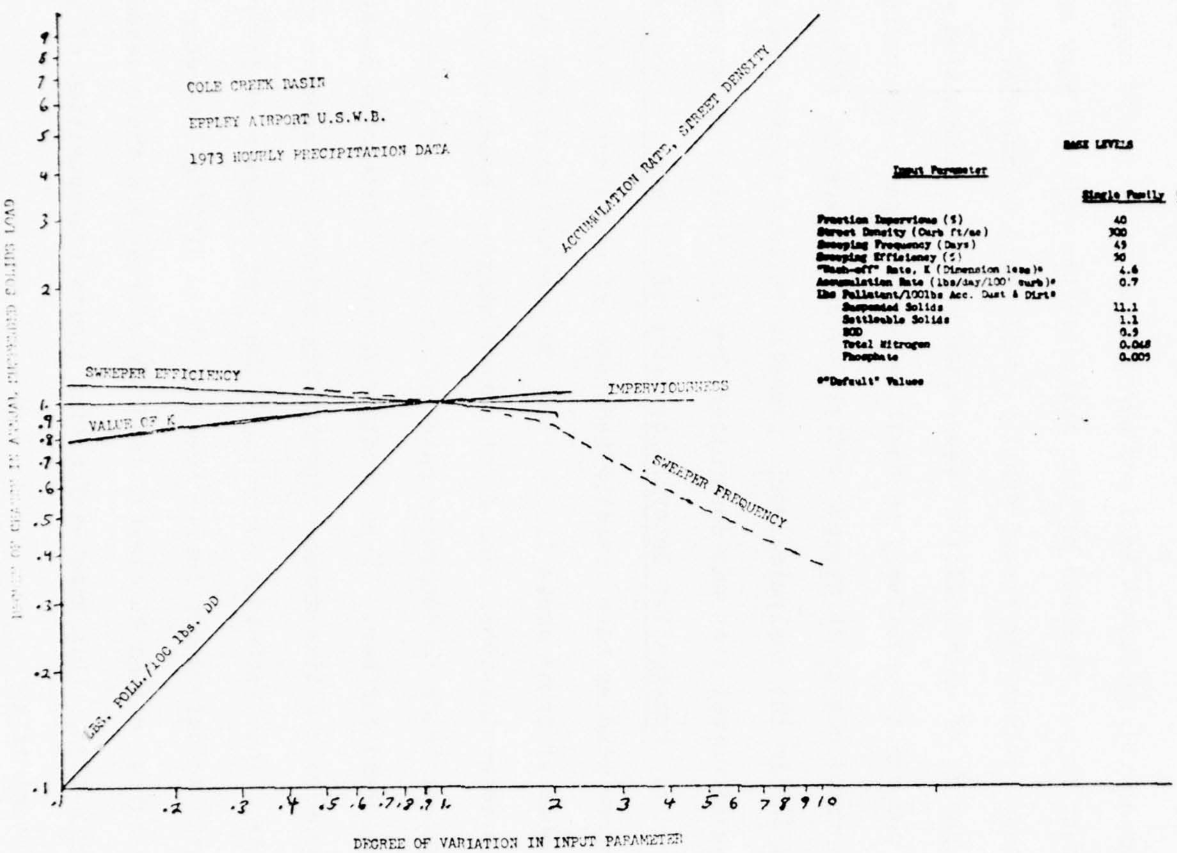
FIGURE 2a, b, c

TIME HISTORIES OF RAINFALL, RUNOFF, AND STORAGE

input value was then varied, one at a time, as a percentage of the base, both smaller and larger, to measure the resultant change in output. The results of this analysis are shown on Figures 3 and 4 for annual pollutant load and average pollutant runoff concentration, respectively. As shown by this analysis, the model is very sensitive to input values for street density, daily rate of material accumulation, and pounds of each pollutant associated with the accumulated material. The program is relatively insensitive to all other input values. A concurrent change in sweeper efficiency and frequency, although not included in the analysis, would probably reflect a much greater change in model output than was determined from the individual analysis.

f. Methods for Determining Rates of Pollutant Accumulation. Research studies have investigated rates of pollutant accumulation in a number of urban areas (1, 8, 13). Two methods have been used for these determinations. The first method utilizes measured runoff pollutant loads to determine rates of accumulation of the pollutants on the land surface. These studies require an extensive sampling program with a time-summed product from several consecutive runoff events. This technique is probably the most accurate as far as defining the actual runoff load. However, it is difficult to work backwards from output values to clearly identify sources and their associated contribution. This quasi-definition limits transposition of the resultant data.

The second method consists of sampling potential pollutants "in situ". This method defines exactly what material accumulates on a

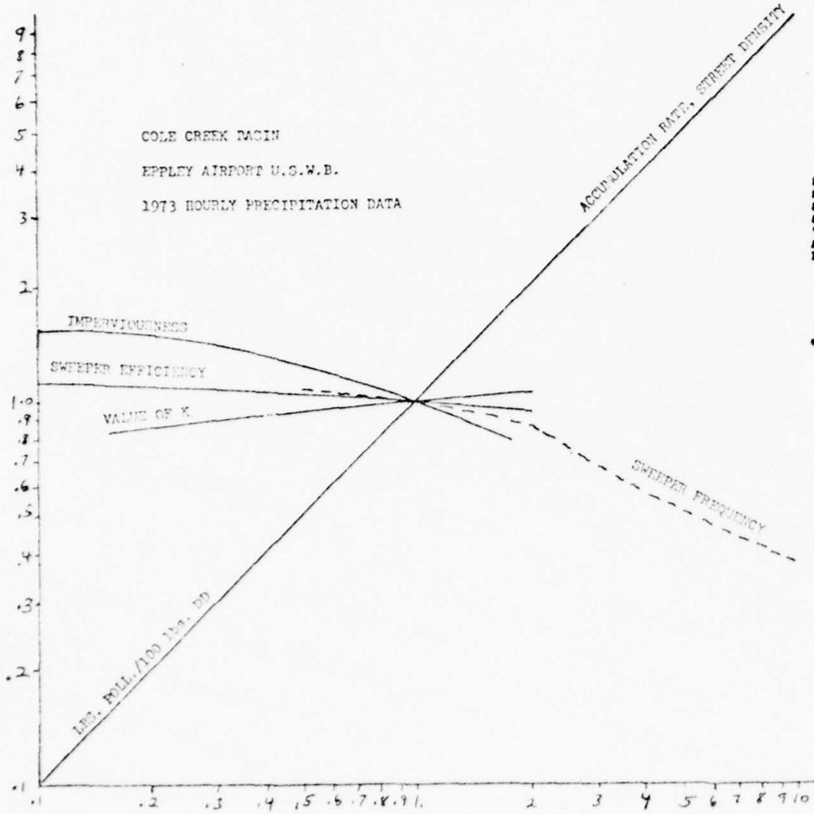


BASE LEVELS

Input Parameter	Land Use: Single Family	Multi-Family	Commercial	Open
Fraction Impervious (%)	40	55	80	2
Street Density (Curb ft/ac)	300	300	100	20
Sweeping Frequency (Days)	45	45	7	100
Sweeping Efficiency (%)	50	50	90	90
"Wash-off" Rate, K (Dimension less)*	4.6	4.6	4.6	4.6
Accumulation Rate (lbs/day/100' curb)*	0.7	2.3	3.3	1.5
lbs Pollutant/100lbs Acc. Dust & Dirt*				
Suspended Solids	11.1	8.0	17.0	11.1
Settleable Solids	1.1	0.8	1.7	1.1
BOD	0.5	0.36	0.77	0.5
Total Nitrogen	0.048	0.061	0.041	0.048
Phosphate	0.005	0.005	0.007	0.005

*"Default" Values

FIGURE 3 - "STORM" SENSITIVITY ANALYSIS, CHANGE IN WASHOFF LOADING



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Total Nitrogen	0.048	0.061	0.041	0.048
Phosphate	0.005	0.005	0.007	0.005

*"Default" Values

FIGURE 4 - "STORM" SENSITIVITY ANALYSIS, CHANGE IN AVERAGE ANNUAL CONCENTRATION

given land surface area. The major advantages of this method include:

1. A limited number of personnel can sample several sectors.
2. Sampling can be done on a defined schedule.
3. To a large degree, the sampling period necessary for a statistically significant number of samples is reduced.

The ideal situation, of course, is a combination of both methods. However, constraints on time and available personnel necessitated use of the second method in this study.

SECTION III

DATA ACQUISITION

SECTION III - DATA ACQUISITION

3.1. Outline of Sample Collection Program.

Two separate but interrelated programs were established to acquire data. The first was a cooperative effort with the City of Omaha to measure the quantity and rate at which debris accumulates on streets. Several pre-selected sectors of the city were swept approximately every two weeks during the study period with a mechanical "street sweeper." The debris collected by the sweeper was transferred to a truck, taken to a scale and weighed. Each sector was swept approximately five times. The needs of this program were used to establish the number and size of sectors to be studied.

The second program was established to identify the types and relative "strength" of the pollutants associated with the street debris. "Strength" is defined as the pounds of a pollutant per 100 pounds of street debris. Samples were collected by hand sweeping several 4 by 5 foot plots within the same sectors selected for the first program. These samples were collected by "hand sweeping" because mechanical sweepers pick up a greater percentage of larger particles than finer particles from the streets. Thus, mechanical sweeper samples are not representative of the debris "in situ". An average of three samples were collected from each studied sector during the period of July to September 1974. The total number of samples collected was limited in order to permit an extensive analysis of each sample for chemical, biological, and bacteriological constituents but still keep laboratory costs within reason.

3.2. Selection of Urban Sectors for Study.

The type, location, size, and number of urban sectors used in the sampling program were established after reviewing existing city zoning maps, discussing the existing street sweeping program and proposed level of support with City of Omaha officials, and a field reconnaissance of several potential sectors. Eight residential and two commercial areas were selected for the study. A summary of some physical characteristics of the selected study sectors are included in Table 1. The major considerations in making the final sector selection were:

1. The City of Omaha would provide one sweeper and driver and one "eductor" truck and driver to the operation on a full-time basis to assure uniformity in data collection and maximum control of the operation.

2. The size of each selected sector would be approximately equivalent to a one day sweeping operation and would have essentially the same boundaries as previously established by the city for snow removal and street sweeping. This would allow the manpower and equipment to be utilized efficiently. Also, the preestablished boundaries would reduce the possibility that portions of the area would be accidentally swept under the regular sweeping program.

3. The selected sectors would consist of only one type of urban land use (single family residential, multifamily residential, commercial, industrial, or open land) to the extent possible.

TABLE 1

PHYSICAL DESCRIPTION OF STUDY SECTORS

Sector Number	Major Land Use[1/]	Socio-Economic Level[2/]	Improvements Age[3/]	Improvements Density (Ft^2/Ac)	Improvements Density (Stru/Ac)	Imperviousness (%)	Vehicular Parking	Vegetation Age[4/]	Vegetation Coverage Land (%)	Vegetation Coverage Street (%)	Street Type[5/]	Street Repair[6/]	Street Curb Density (Ft/Ac)
BD-6	SF	LM	O	5,600	4.5	32	On & Off St.	M	30	33	C,A	G,F	348
CC-8	SF	L,LM	O	5,300	4.4	32	On & Off St.	M	30	38	C,A,B,G	F,P	310
SD-4	SF	LM	O	5,000	4.0	30	Off Street	M	20	12	C,A,B	F,G	365
WB-7	SF	UM	M	4,500	1.5	17	Off Street	M	7	3	C,A,G,	G	224
BA-1	SF	M,UM	N	5,000	1.1	22	Off Street	Y	1	0	C	G,E	305
MB-2	SF	M,UM	N	5,000	3.3	28	Off Street	Y	1	0	C	G,E	310
MC-2	SF	UM	N	5,200	2.8	30	Off Street	Y	1	0	C	G,E	295
NB-1	SF	M,LM	N,M	5,100	3.8	32	Off Street	Y	4	1	C,G	G,F	304
BB-1	C	-	N	10,000	-	65	Off Street	Y	1	0	C	G,E	243
Center St.-	C	-	O	4,800	2.3	70	Off Street	M	3	1	C,A	F,G	-

1/ SF, Single Family Residential
C, Commercial

2/ L, Lower Income
LM, Lower Middle Income
M, Middle Income
UM, Upper Middle Income

3/ O, Older Developments for Urban Area
M, Middle Age Developments for Urban Area
N, Newer Developments for Urban Area

4/ M, Mature
Y, Young

5/ C, Concrete
A, Asphalt
B, Brick
G, Gravel (Gravel streets were not swept).

6/ E, Excellent
G, Good
F, Fair
P, Poor

4. Most of the study emphasis would be directed toward the single family residential land use because a majority of the city is in this category. It was considered that if residential pollution loads could be defined adequately then comparable results from the literature could be used to define pollution loadings for the other land uses based on these results.

5. Any data collection in industrial areas would have required modification of sweeping procedures because most of the streets in these areas do not have curbs.

6. None of the major multifamily residential developments would be selected for the sweeping program because the streets within the complex are part of a private development and not maintained by the City.

3.3. Methods of Sample Collection.

a. Street Sweeping. The ten urban sectors were swept on a rotating sequential basis for the two and one-half month sampling period running from mid-June to the first of September. The assigned manpower and equipment from the City consisted of a Mobil TE4 mechanical street sweeper, one "broom" operator, an "eductor" truck, and one truck driver. The same equipment and personnel were used throughout the study. The mechanical features of the sweeper include:

1. Seven and one-half feet sweeping swath.
2. Water spray system.
3. Four cubic yard hopper capacity.
4. 1 - 12 mph sweeping speed.
5. 55 mph maximum travel speed.

Normal sweeper operation procedures were followed during the test period. A questionnaire was completed by both the "broom" operator and truck driver to summarize each day's sweeping operation. These questionnaires were used to determine

1. What portion of the sector was swept.
2. What type of material was picked up by the broom.
3. The volume of water used in the water spray system.
4. The amount of on-street parking during sweeping.
5. The weight of material picked up from the sector.

The quantity of material collected during each sweeping operation was determined by weighing the loaded truck at a scale. A constant tare weight was used for the truck throughout the study because the scale was not near the dump site for the debris. It was considered that any changes in tare weight would generally be less than 5 percent of the debris load. If the load was small, some adjustment was made in the tare weight based on the fuel level of the truck at weigh in. Each weight ticket was affixed to the questionnaire.

At the start of the third round of sweeping, a sample was collected each day to send to the laboratory for a determination of the moisture content of the swept debris and also the size distribution of the organic and inorganic material. The analysis procedure is discussed later in this report. All samples were collected by the operators, placed in plastic bags, and sealed. Twice weekly these samples were collected from the City maintenance yard and taken to the laboratory for analysis. Moisture content was determined in order to adjust all measured weights to an

ovendry basis. The moisture content was estimated for the first two rounds of sweeping.

b. Hand Sweeping. Hand sweeping samples were collected from each sector at intermittent time intervals. Since the area from which the hand sweeping samples were collected was small in comparison to the total sector area, the entire sector was reconnaissanced each time before a representative street was selected for sampling.

A sample was collected by sweeping several 4 X 5 feet plots along the curb of the street. The spacing between plots varied depending upon the street selected for sampling but normally the following procedure was utilized.

> An initial reference point was established approximately 15 feet, paced measurement, from a street corner. From this reference point, a rectangular 4 X 5 feet plot was laid out by tape. The 5 foot dimension was parallel to the curb. The plot was then swept in the direction of "from the street to the curb" with a standard bristle broom. The debris was then swept into a dust pan with a whisk broom and put in a plastic bag. The whisk broom was also used to remove as much material as possible from cracks in the pavement. The sweeping criteria was "as clean as possible". A second plot was laid out approximately 150 feet down the street from the first plot. This same spacing between plots was continued to the end of the block. The same procedure was repeated for each subsequent block. The sampling continued block by block until about three to four pounds of debris was collected. The

sampling distance normally ranged from a minimum of one block to a maximum of about six blocks depending upon the debris loading on the street.

In some cases, the first sampling plot was established at the head of a drainage and the aforementioned procedure was followed to the base of the drainage. The location of each sampling plot was recorded on the laboratory analysis sheet included with each sample.

Hand sweeping samples were only collected in the eight residential sectors. The commercial sectors were not sampled because both are heavy traffic areas and extensive measures would have been necessary to assure the safety of sampling personnel. It was believed that such efforts would not have gainfully benefited study results. Other studies have shown that the major difference between residential and commercial areas is only the rate at which the debris accumulates (8, 13).

3.4. Laboratory Analysis Procedures.

a. General. Laboratory analysis of the dry solid samples was performed by the Missouri River Division Laboratory in Omaha, Nebraska. The analyses included: 1) a particle size analysis of both the organic and inorganic material for all samples and 2) a quality analysis of the material finer than the U.S. Standard number 10 sieve for the "hand sweeping" samples. Laboratory sample preparation procedures and analysis methods are discussed in the following sub-units.

b. Method of Particle Size Analysis. The particle size distribution of the debris was determined by ro-tapping each ovendry sample through a nested set of sieves. The sieve nest consisted of U.S.

Standard sieve numbers; 4, 10, 20, 70, 140 and 270. Standard methods as outlined in EM 1110-2-1906, were used for the sieve analysis with the following exceptions or additions:

(1) The samples were not disaggregated by a mortar and pestle prior to sieving. This activity would have disproportionally pulverized the vegetative matter. Aggregated soil was broken up by hand.

(2) The material passing the No. 270 sieve was retained and included as part of the other determinations.

(3) The volatile fraction of the material retained on each sieve was determined as outlined in Section 224G, 13th Ed. of Standard Methods for the Examination of Water and Wastewater.

c. Method of Sample Preparation for Quality Analysis. The analysis of the quality constituents associated with the street debris was aimed at 1) measuring the level of pollution during the runoff period and 2) measuring the residual level of pollution if the runoff was collected in a sedimentation basin. A somewhat arbitrary but determinative laboratory procedure was established to synthesize each level of pollution. The "hand sweeping" samples were prepared for simulating these levels of pollution in the following manner:

1. Runoff Level. After sieving the ovendry sample, 100 grams of the dry solids was recomposited on the same fractional dry weight basis as determined in the sieve analysis. The portion of the total sample larger than the U.S. Standard Number 10 sieve was kept separate from the portion finer than this sieve. The larger material was then washed with one liter of distilled water

using the number 10 sieve as a screening medium. The liquid and the debris passing through the sieve was collected. The portion of the 100 grams finer than the number 10 sieve was added to this liquid. The resultant slurry was then rapid mixed for a five minute period. Aliquot portions were drawn from the slurry for biological and chemical analyses.

2. Residual Level. One hundred grams of ovendry solids finer than the number 10 sieve was added to 1 liter of distilled water. The mixture was rapid mixed for a period of five minutes and poured into a glass vessel to a depth of at least 20 centimeters. The mixture was then allowed to stand quiescent for one hour. At the end of one hour, sufficient liquid was siphoned from a point halfway between the surface and settled deposits for a quality analyses. Any particulate matter remaining in suspension at this level was considered to represent suspended solids in wastewater treatment procedures. The procedure for separating suspended solids from settleable solids is outlined in section 224F of Standard Methods.

d. Quality Parameters Measured in the Laboratory. A summary of the quality parameters as measured in the laboratory and by the test procedures are described in Table 2. An intended test for nitrates was inadvertently deleted from the laboratory tests. However, other studies have shown that nitrates comprise only about one percent of the total nitrogen in street debris (13). All laboratory results are reported as pounds of pollutant per 100 pounds of debris

finer than 2.0 mm or per 100 pounds of total debris. Individual laboratory results are included in the attached appendix.

TABLE 2
SUMMARY OF PARAMETERS AND LABORATORY METHODS
FOR ANALYZING THE QUALITY OF STREET DEBRIS SAMPLES

Quality Parameter	Laboratory Procedure [1/]	Sample Preparation [2/]	Results Reported as
Sus. Solids	Nonfiltrable Residue	A, B	gms/100 gms passing U.S. Standard No. 10 Sieve
Vol. Sus. Solids	Ignition at 550°C	A, B	Same
Biochemical Oxygen Demand	Standard 5-day	A, B	Same
Chemical Oxygen Demand	Standard	A, B	Same
Phosphorus	Acid Hydrolysis	A, B	Same
Nitrogen	Total Kjeldahl	A, B	Same
Total Coliforms	Membrane Filter	Total	Colonies/100 grams of total sample
Chromium	Spectrophotometric	A, B	gms/100 gms passing U.S. Standard No. 10 Sieve
Lead	Spectrophotometric	A, B	Same
Mercury	Perkin-Elmer Mercury Analyser, Cold Vapor	A, B [3/]	Same
Nickel	Heptoxime	A, B	Same
Zinc	Spectrophotometric	A, B	Same

1/ Standard Methods for the Examination of Water and Wastewater, 13th Edition, with exception of mercury.

2/ Method A - Residual level of pollution (Section 224F, Standard Methods).
Method B - Runoff level of pollution (Rapid Mix).

3/ Mercury lost from samples between analysis of A and B.

SECTION IV

DATA EVALUATION

SECTION IV - DATA EVALUATION

4.1. General.

One general conclusion of the street debris sampling program was an indication that the major difference between the individual residential study sectors related to the amount of debris on the streets. More specifically, there appears to be a direct relationship between the age of the residential sector and the quantity of street debris. This conclusion was also verified by other studies (13). However, there was one exception to this age-accumulation relationship. Sector NB-1, which represents a relatively new or young residential land use development, was found to have approximately the same amount of debris on the streets as older Sectors SD-4 and WB-7. Thus, other physical factors such as those described in Table 1 may also affect the quantity of debris accumulating on the street. To simplify evaluation of the collected data, the studied residential sectors were grouped into two age categories--"new" and "old". This grouping was done to compare differences in the rate of debris accumulation and also to show the time dependent change in probable runoff quality as a given residential area ages. Sectors CC-8, SD-4, BD-6 and WB-7 were grouped in the older residential classification while sectors NB-1, BA-1, MB-2, and MC-2 were classified as new developments. All determinations for the grouped categories weight each sector equally. The data collected in this study is evaluated and compared to reported findings in the literature in the following discussion. Since the only

data collected in the commercial sectors was from street sweepers, most of the conclusions are based on findings from the residential sectors.

4.2. Comparison of Data Collected in Residential Sectors.

A relative comparison between each residential sector was determined by ranking the sectors for each measured parameter. This ranking is included in Table 3. The basic data supporting these rankings is included in the appendix. The numbering sequence is from worst or highest level of pollution (1) to the least or lowest level (8). The laboratory results from the "hand sweeping" samples were composited by weighting the sampling area of the individual samples. As previously discussed, quantity of debris collected by the street sweeper in the "old" sectors was generally greater than the "new" grouping but there was no distinguishable pattern established between the two groupings for the quality analyses. Quite definitely, any inferences based on the laboratory analyses must be cognizant of the limited sampling that was conducted in each sector. However, since most of the measured quality parameters do not differ greatly between any of the sectors, it was concluded that an overall composite could be considered representative of the pollutant "strength" of street debris within the City of Omaha.

4.3. Debris on the Street.

a. Total Debris. The quantity of ovendry debris collected by the street sweepers during the summer sweeping program in the residential sectors ranged from a high of 870 pounds per curb mile swept

Table 3

Ranking* of Residential Study Sectors for Measured Pollution Parameters

	GROUPED AGE CLASSIFICATION AND SECTOR IDENTIFICATION NUMBER								ORDER OF DIFFERENCE***
	OLD				NEW				
	CC-8	SD-4	BD-6	WB-7	NB-1	BA-1	MB-2	MC-2	
Debris Collected by Sweeping Number									
1	1	4	2	4	3	6	7	8	7.7
2	1	3	2	5	4	6	7	8	26.8
3	1	5	2	4	3	6	7	8	51.2
4	1	5	2	4	3	-	6	7	16.5
5	-	4	1	2	3	5	6	-	4.2
Avg.	1.0	4.2	1.8	3.8	3.2	5.8	6.6	7.8	
Pollutional "Strength" of Street Debris **									
Sus. Solids	8	3	5	2	7	6	1	4	2.9
Settl. Solids	3	6	4	5	8	2	1	7	4.8
Vol. Sus. Solids	7	2	5	3	6	8	1	4	6.6
Vol. Settl. Solids	1	4	2	3	7	6	5	8	4.9
BOD_5 Sus. Sol.	7	2	6	3	4	8	1	5	7.4
BOD_5 Settl. Sol.	1	6	3	2	4	5	-	7	9.4
COD Sus. Sol.	7	2	6	3	4	8	1	5	11.8
COD Settl. Sol	1	3	2	4	5	6	7	8	14.1
Ext. PO_4 Sus Sol.	7	6	4	5	3	8	1	2	2.4
Ext. PO_4 Settl.Sol	1	5	4	3	7	6	2	8	2.2
Tot. Kjel.N Sus Sol	7	3	4	6	5	8	2	1	23.8
Tot. Kjel.N Settl Sol	2	3	1	4	5	6	8	7	46.7
Total Coliforms	4	6	3	2	7	8	1	5	527.8
Zinc Sus Sol.	2	6	1	7	4	8	3	5	2.2
Zinc Settl. Sol.	1	2	5	6	3	8	4	7	5.7
Lead Sus. Sol	2	6.5	6.5	3	4	8	5	1	3.4
Lead Settl. Sol.	1	3	2	8	5	7	6	4	13.4
Nickel Sus. Sol	5.5	8	5.5	3	4	7	2	1	2.6
Nickel Settl. Sol	3	5	4	6	8	2	1	7	10.4
Mercury Sus. Sol.	3	4	2	6	1	7	8	4	13.6
Chromium Sus Sol	4	8	7	2	5.5	3	1	5.5	3.1
Chromium Settl Sol	2	7	3	5	8	4	1	6	5.0
Avg.	3.6	4.6	3.9	4.1	5.2	6.3	2.8	5.1	
Total Avg.	2.3	4.4	2.9	3.9	4.2	6.0	4.7	6.4	
Ranking for									
Total Debris	1	5	2	4	3	6	7	8	
Quality	2	5	3	4	7	8	1	6	
Overall	1	5	2	3	4	7	6	8	

* (1) Highest value measured, (8) lowest value measured
** Pounds of pollutant per 100 pounds of debris $\leq$ 2.0 mm particle size.
*** Highest value divided by lowest value.

in Sector CC-8 to a low of 20 pounds per curb mile swept in Sector MC-2. The quantity in the commercial sectors ranged from a high of 3050 pounds in Sector BB-1 to a low of 170 pounds per curb mile swept also in Sector BB-1. The chronology of the debris collected by the street sweeper is summarized on Plate 2. The maximum, minimum, and average quantity of debris collected by the street sweeper in each sector are summarized on Plate 3.

Since street sweepers do not pick up 100 percent of the street debris, the total quantity of debris on the street was estimated from the hand sweeping samples. Based on these estimates, the average accumulation of debris on the streets during the sampling program was 765 pounds per curb mile for the residential sectors classified as "old" and 150 pounds per curb mile for the "new" residential sectors. Sector CC-8 had the highest determined street loading at 1660 pounds per curb mile while Sector MB-2 had the lowest at 65 pounds per curb mile. The average street loading for residential areas as determined from another study, was 1200 pounds per curb mile (13). However, three of the ten cities included in this study had street loadings comparable to the loadings found in Omaha. These cities are Seattle, Washington; Atlanta, Georgia; and Tulsa, Oklahoma. Average street debris loadings reported for these cities were 460, 430, and 330 pounds per curb mile in the same respective order.

b. Size Distribution and Volatile Fraction of Debris. The size distribution of the organic and inorganic fractions is considered an important descriptive parameter of the street debris. This information

is particularly beneficial for assessments involving particle transport but perhaps may be even more beneficial eventually as a measure of the "fixation" potential for pollutants. For example, composited results from investigations in ten major metropolitan areas indicate that the pollutant "strength" of the finer particles is several times greater than it is for the larger particles (13). "Strength" is defined in this context as the weight of a pollutant per unit weight of the debris to which it is fixed. This is to be expected since the surface area and the fixative forces (adsorption, absorption, etc.) increase with diminishing particle size.

The size distribution of the inorganic debris on the streets was found to be essentially log normal. The mean size of the particles ranged from 0.26 mm in sector CC-8 to 0.9 mm in sector NB-1. Particles of this size are classified as medium and coarse sand, respectively. In fact, most of the inorganic debris was comprised of sand and gravel sized particles. The silt and clay sized fraction ranged from 6 to 20 percent of the total inorganic sample. The size distribution of the composited "hand sweeping" samples for each sector is plotted on Plate 4.

The size distribution of the organic debris was not found to be log normal over the full range of measured particles sizes. The debris passing the No. 10 sieve, however, appears to have essentially a log normal distribution. Organic material passing the No. 10 sieve is generally in some state of decompostion because this sieve is approximately the limiting transverse diameter for nondecomposed grass clippings and other small vegetative stems. This conclusion is based on inspection

of many sieved samples. It must be remembered that for nonspherical particles such as grass and other vegetative material, the sieve analysis is not a true measure of particle size. Nevertheless, the mean particle size of the organic material, as determined by the sieve analysis, ranged from 0.8 mm for sector CC-8 to approximately 4.0 mm for sectors BD-6 and WB-7. Only a very small percentage of the organic debris was determined to be finer than silt sized particles. The percentage of particles this fine ranged from 1.5 to about 18 percent. The size distribution of the organic fraction of the street debris for each residential sector is plotted on Plate 5.

In most cases, the major portion of the organic debris was retained on the No. 4 or No. 10 sieves. Since it was concluded previously that the organic debris retained on these sieves is essentially in a nondecomposed state, most of the organic material on the street probably does not have an immediate oxygen consuming impact upon a drainage system during a runoff event. Material this large, though, is susceptible to entrapment which could either slowly add to later oxygen demands on the system or after decay and a subsequent runoff event add a concentrated impact. This latter situation is normally referred to as the "first flush" effect. The major source for such entrapment in urban areas is storm sewer catch basins.

The next step in the evaluation was to composite all sieve analyses on the basis of the previously established age groupings. The resultant size distribution curves for both the organic and inorganic fractions were essentially identical for the two groupings. The grouped composite

curves are shown on Plate 6. The only significant difference between the two groupings is that the large organic debris in the "old" sectors was retained on the No. 4 sieve while in the "new" sectors some of the organic material passed this sieve and was retained on the No. 10 sieve. The reason for this difference was explained by examination of the sieved samples. The large nondecomposed organic matter in the "old" sectors was largely leaves and small tree branches which are not able to pass the No. 4 sieve. The nondecomposed material in the "new" sectors is mainly grass clippings. Some of these grass clippings pass through the No. 4 sieve during ro-tapping.

The percent of organic debris was slightly greater on a total dry weight basis in the "old" sectors than in the "new" sectors. The composited organic fractions were 21.8 and 15.0 percent for the "old" and "new" sectors, respectively. However, the total quantity of organic debris on the streets in the "old" grouping was several times greater than the "new" residential grouping. The average quantity of ovendry organic material on the "old" streets was 167 pounds per curb mile of street. The comparable quantity in the "new" sectors was only 22 pounds per curb mile. These estimates are based on the "hand sweeping" samples.

The particle size distribution of the total street debris as measured for Omaha is comparable to the size distribution measured in other cities by the Environmental Protection Agency (13). A comparison of the size distribution analysis of the five cities included in the EPA Report and the measured Omaha data is shown in Table 4.

Some extrapolation of Omaha Data was necessary in the silt size range. It is significant to note that less than one percent of the debris collected in each city consisted of clay size particles. This fact is important in some of the evaluations discussed later in this report.

Table 4

COMPARISON OF MEASURED SIZE DISTRIBUTION ANALYSES OF STREET DEBRIS

Particle Size Range (Microns)	Percent of Particles in Size Range for City					
	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa	Omaha
> 4800	12.0	-	17.4	-	-	14.0
2000-4800	12.1	10.1	4.6	14.8	37.1	8.0
840-2000	40.8	7.3	6.0	6.6	9.4	14.0
246-840	20.4	20.9	22.3	30.9	16.7	29.0
104-246	5.5	15.5	20.3	29.5	17.1	15.5
43-104	1.3	20.3	11.5	10.1	12.0	11.0
30-43	4.2	13.3	10.1	5.1	3.7	2.8
14-30	2.0	7.9	4.4	1.8	3.0	1.4
4-14	1.2	4.7	2.6	0.9	0.9	0.9
< 4	0.5	-	0.9	0.3	0.1	0.5

c. Measured Pollution on Street. Defining the quantity of a pollutant associated with a unit weight of street debris is essentially a matter of definition. In this study the two major pollution levels of concern were:

1. The pollutants that remain attached to particulate matter of the size that would probably be transported in suspension by water

flow during runoff but would rapidly settle out or deposit in a nontransit state.

2. The pollutants in solution and those associated with the fine particulate matter that would remain in suspension during both a transit period and afterwards in some near collodial state. Since neither the total pollution load of the debris nor the soluble load (particles $\leq$ 0.45 microns) was measured, estimates were developed for each of these levels based on a combined evaluation of results published in the literature and extrapolation of the data collected for this study. The meaning and conclusions of these estimates are discussed later in the report.

The laboratory measurements indicate that most of the measured pollution load was associated with the settleable solid fraction of the street debris. The average computed pollution loading on the street for the two residential groupings is summarized in Table 5 for each measured quality parameter. Even though most of the pollution was found to be associated with the settleable solids, the pollutant concentration (pounds of pollutant per pound of dry solids in analyzed sample) of the suspendable portion of the debris was much greater than the concentration of the settleable debris. The pollutant concentration for the two measured pollution levels are summarized in Table 6. The pollutant concentration of the suspended pollution level was determined to be approximately the same for both the "old" and "new" residential sectors. However, the comparative pollutant concentration of the settleable debris was significantly different for many of the measured parameters.

Table 5

AVERAGE MEASURED POLLUTION LOAD ON RESIDENTIAL STREETS
IN POUNDS PER CURB MILE OF STREET

Measured Parameter	Pollution Loading Values by Residential Age Grouping			
	Suspended		Settleable	
	"Old"	"New"	"Old"	"New"
Total Solids	6.0	1.5	97.1	25.7
Volatile Solids	2.49	.58	15.0	1.56
BOD_5	1.92	.46	4.64	0.40
COD	3.13	.68	19.7	0.78
Extractable PO_4	0.068	0.025	0.35	0.058
Kjeldahl Nitrogen	0.089	0.040	0.35	0.016
Coliforms $X10^8$				
Zinc	0.0031	0.00061	0.0225	0.0025
Lead	0.0076	0.0017	0.0468	0.00356
Nickel	0.00028	0.000077	0.00133	0.00034
Mercury	0.00059	0.00049	*	*
Chromium	0.00015	0.00004	0.00124	0.000256

Table 6

MEASURED POLLUTANT CONCENTRATION OF STREET DEBRIS IN POUNDS OF POLLUTANT PER POUND OF TOTAL SOLIDS

Constituent	Concentration by Residential Age Grouping			
	Suspended		Settleable	
	"Old"	"New"	"Old"	"New"
BOD_5	0.32	0.31	0.048	0.016
COD	0.52	0.45	0.203	0.031
Extractable PO_4	0.0113	0.0167	0.0036	0.0023
Kjeldahl Nitrogen	0.0148	0.0267	0.0035	0.00062
Zinc	0.00052	0.00041	0.00023	0.00010
Lead	0.00127	0.00111	0.00048	0.00014
Nickel	0.000047	0.000051	0.000014	0.000013
Mercury	0.000098	0.000267	-	-
Chromium	0.000025	0.000027	0.000013	0.000010

The difference, except for lead, is most significant in the quality parameters that in some manner relate to the organic fraction of the debris; i.e., BOD_5, COD, and Kjeldahl Nitrogen. Much of this difference can probably be explained from the data presented in Table 5. More specifically, the settleable fraction in the "old" category was comprised of 15.5 percent (15.0/97.1) organic material while only 6 percent (1.56/25.7) of the settleable material in the "new" category was organic. Thus, when the pollution concentration of the organic parameters was derived relative to total solids, the concentration derived for the "new" grouping was less. Somewhat better agreement between the two groupings for BOD_5, COD, and Kjeldahl Nitrogen was found when measured values for these parameters were compared as a fraction of volatile solids.

d. Total Pollution on Street. Not all of the pollution in the street debris was measured by the laboratory analyses used in this study. The results of the investigations by the Environmental Protection Agency indicate that the total pollution load may be significantly higher than was measured from the settleable and finer debris (13). An estimate was developed for the total pollution load based on the results of the EPA studies. The results are included in Table 7. The estimates for the major pollution parameters are considered reasonable. However, the orders of magnitude differences for the heavy metals makes these estimates suspect. It is not known whether the actual heavy metal loading in Omaha, Nebraska is much less than the levels measured in the cities sampled by EPA, or whether the laboratory findings are in

error. It is believed that the measured heavy metal loading should be at least 20 to 25 percent of the total. Nevertheless, the estimated values are used for subsequent evaluations.

Table 7

COMPARISON OF MEASURED AND ESTIMATED
TOTAL POLLUTION LOAD FOR RESIDENTIAL STREET DEBRIS
IN OMAHA, NEBRASKA[1]

Pollution Parameter	Pollution Load			
	Pounds Per Curb Mile		Pounds Per Acre [3]	
	Total	Measured[4]	Total	Measured
Total Solids	456.5[5]	65.1	26.8[5]	3.8
Volatile Solids	84.0[5]	9.8	4.9[5]	0.58
BOD_5	10.5	3.7	0.62	0.21
COD	24.6	12.1	1.44	0.72
Ext. PO_4	0.35	0.25	0.020	0.015
Kjel. Nit.	0.74	0.24	0.043	0.014
Coliforms X 10^8 [2]	24.2 [5]	-	1.42[5]	
Zinc	0.21	0.014	0.012	0.0008
Lead	0.19	0.030	0.011	0.0017
Nickel	0.016	0.001	0.0009	0.00006
Chromium	0.036	0.00035	0.0021	0.00005

1. Average values for all studied residential sectors.

2. Colony count.

3. Average street density of 310 curb feet per acre.

4. Includes settleable and finer debris.

5. Measured values.

e. Distribution of Pollutants by Size Fraction. During a precipitation wetting and runoff event, the street debris assumes some mass distribution of particulate matter while suspended in runoff. The particulates, as separated, range in size from molecular to material much larger than 2 mm in diameter. Each size fraction is comprised of both organic and inorganic material. Consequently, each fraction has some associated pollution load.

An estimation of the wetted particulate and associated pollutant disassociation would be beneficial for evaluating the contribution and water quality impact of the street debris. Potential applications include:

1. Simulation of pollutant transport and loading through the use of existing particulate transport theories;

2. Relating measured runoff pollution loads to "in situ" pollution sources; and

3. Estimating the effectiveness of physical treatment systems; e.g., screening, in reducing pollution.

The degree of disassociation and distribution of the measured quality parameters by particle size was estimated using the measured laboratory results and the values computed for total pollution load from the EPA study. The data for the suspended and finer material was adjusted slightly, because of a discrepancy in laboratory procedures between the measurement of the suspended load and the

settleable plus suspended pollution load. (The laboratory procedure for measuring the suspended load only did not include washing of the debris larger than the U. S. Standard No. 10 sieve. The larger debris was washed when the settleable and finer fraction load was measured.) The amount of adjustment was based on the results of two laboratory measurements of washed plus 10 debris. The distribution of the pollutants by particle size is plotted on Plate 7. Since laboratory procedures were not initially established to measure the distributed load phenomena, the results, as shown on Plate 7, are somewhat superficial. The curves, however, are considered representative of potential findings. Their application and use are more fully qualified in this report. The results for three particle size ranges are compared to EPA findings in Table 8.

TABLE 8

COMPARISON OF MEASURED POLLUTION LOADS FOR VARIOUS PARTICLE SIZE FRACTIONS OF STREET DEBRIS IN POUNDS PER CURB MILE

Pollution Parameter	City[1/]					
	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa	Omaha
(Total Pollution Load)						
Total Solids	2700	1400	1000	430	330	456
Volatile Solids	180	150	96	18	19	84
BOD_5	12	2.9	61[2/]	1.9	14	10.9
COD	48	29	20[2/]	13	30	25.5
Kjel. Nit.	1.4	1.2	1.9	0.5	0.7	0.7
Ext. PO_4	0.27	0.25	1.0	0.26	0.54	0.35
(Pollution Load for Debris < 104 μ Particle Size)						
Total Solids	248.4	646.8	295	78.3	65.0	88.9
Volatile Solids	78.3	65.2	41.8	11.2	8.8	8.7
BOD_5	5.0	1.2	25.4[2/]	0.8	5.8	3.4
COD	32.5	19.6	13.5[2/]	8.8	20.3	10.5
Kjel. Nit.	0.25	0.22	0.34	0.23	0.32	0.22
Ext. PO_4	0.23	0.21	0.86	0.22	0.46	0.28
(Pollution Load for Debris < 43 μ Particle Size)						
Total Solids	213.3	362.6	180.0	34.8	25.4	31.9
Volatile Solids	46.1	38.4	24.6	7.7	5.6	4.0
BOD_5	2.9	0.7	14.8[2/]	0.5	3.4	2.4
COD	10.9	6.6	4.5[2/]	3.0	6.8	5.9
Kjel. Nit.	0.01	0.01	0.01	0.14	0.19	0.15
Ext. PO_4	0.15	0.14	0.56	0.15	0.30	0.20

1/ From Reference 13, except Omaha.

2/ Values as reported in Literature.

4.4. Derivation of Input Data for STORM.

a. General. As previously stated, the major reason for collecting and analysing the street debris data was to develop reliable input values for the water quality subroutine in STORM. The data was used to determine input values for:

1. Sweeper efficiency;

2. Rate of debris accumulation; and

3. Pollutant "strength" of the accumulating debris.

The derivation techniques and the resultant input values are discussed in the following paragraphs.

b. Sweeper Efficiency. The efficiency of the street sweeper used in the study was evaluated through a comparison of results from the "hand-sweeping" and "street-sweeping" programs. The "hand-sweeping" results were assumed to represent the true debris conditions for the sector for both debris loading and particle size distribution. The overall sweeper efficiency was determined by dividing the average quantity of debris collected by the street sweeper per curb mile by the average total street loading as determined that the street sweeping efficiency in the "old" residential sectors was approximately 33 percent while the efficiency in the "new" sectors was approximately 59 percent. Sweeper efficiency in the "old" sectors is probably less, because of the type and condition of streets, curbs, and gutters and also because

of significant on-street parking during the period of street sweeping. Because of on-street parking, the broom operator is not able to sweep along the entire curb of the street; thus, the sweeping efficiency per mile of street curb is reduced. These calculated sweeper efficiency values were considered reasonable, based on results of sweeper efficiency tests using test plots in another study. The overall debris removal efficiency for these tests ranged from 11 to 62 percent (13).

Street sweepers appear to pick up larger debris particles more efficiently than finer particles. The composited sieve analyses of the "street sweeper" samples for each residential age grouping had only about 3 percent of inorganic particles finer than silt, while nearly 42 percent of the particles were larger than 2.0 mm. The corresponding hand-sweeping results, representative of the "in situ" state, were 13 and 22 percent respectively. The composited sieve analyses of the "street sweeper" samples are shown on Plate 8. The street sweeper pick-up efficiencies for various size fractions of the debris was estimated using the composited "hand-sweeping" and "street-sweeping" sieve analyses on Plates 6 and 8, respectively, and the overall sweeper efficiencies computed previously. The results are presented in Table 9.

TABLE 9

STREET SWEEPER REMOVAL EFFICIENCY FOR VARIOUS SIZE FRACTIONS OF RESIDENTIAL STREET DEBRIS IN OMAHA, NEBRASKA

Particle Size Range	Computed Sweeper Efficiency in Percent "Old"	"New"
> 2.0 mm	54	100
1.0-2.0 mm	42	89
0.5-1.0 mm	37	56
0.2-0.5 mm	28	32
0.1-0.2 mm	19	18
< 0.1 mm	11	12
Overall	33	59

The size distribution of the debris collected by the mechanical street sweeper in commercial sector BB-1 when plotted on log-normal paper, fell between the "old" and "new" residential inorganic plots. Since the volatile solids determinations for this commercial sector indicate that less than 4 percent of the debris was organic, it was considered that the size distribution plot of the total sample was approximately the same as an inorganic plot. Since the resultant distribution lies between the residential groupings, it was assumed that the sweeper efficiency for this commercial sector was probably somewhere in between the two residential groupings. If so, the size distribution of the debris "in situ" should also approximate that of the inorganic fractions in the residential sectors.

For simplicity, an overall sweeper efficiency of 50 percent and the size fractional efficiency of the "new" residential grouping was assumed as representative for this sector. The resultant computed "in situ" size distribution for BB-1 and the composited size distributions of the mechanical sweeper samples for the two commercial study sectors is shown on Plate 9.

The size distribution of the debris collected along Center Street differed greatly from any of the other study sectors. Therefore, no attempt was made to evaluate the "in situ" size distribution of particles in this sector. Based on mere judgment, the sweeper efficiency along this sector was assumed to be the same as for the "old" residential grouping.

c. Basis for Determining Debris Accumulation Rate on Street. The quantity of debris on the street is known to vary considerably from one location to another and from time period to time period. Research investigations have determined that the expected accumulation at a given time and place is primarily dependent upon (13):

1. Time since last cleaning or rainfall;
2. Season of the year; and
3. Type and physical characteristics of the locale.

On a hypothetical basis, the accumulation and removal of the street debris has been depicted as shown in Figure 5. The only mechanisms by which debris is removed is sweeping and precipitation runoff.

The removal by the sweeper is assumed to be a uniform percentage of the total accumulation. The amount of debris removed by precipitation, however, is dependent upon the intensity and duration of the precipitation event. This is the hypothetical situation for debris accumulation and wash-off that is modeled by STORM. The accumulation rate is assumed to be linear and constant throughout time up to a possible maximum total accumulation of 100 days.

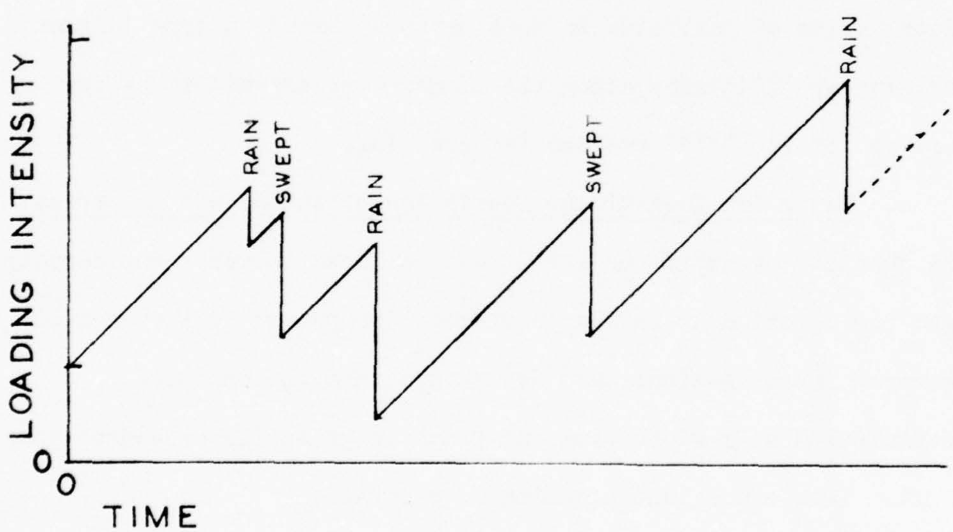

Figure 5: Linear Accumulation of Debris on Street with Removal Mechanisms of Rain and Street Sweeping Only.

From a limited scope investigation of debris accumulation rates by the Environmental Protection Agency, it was determined that the accumulation of debris in a residential land use sector is best described by the equation (13):

$$Y = 426\ e^{.0565X} \qquad (8)$$

Where Y = pounds of accumulated debris per curb mile

X = number of days since the street was last cleaned by sweeping or precipitation.

The equation is presented graphically in Figure 6. As shown by the plot, the accumulation rate after the first day is approximately linear over the time interval included for the graph. After reviewing the methods used by EPA to evaluate their data, it is probable that the large first day accumulation is either 1) the residue left on the street after sweeping, 2) debris not flushed from the street by the assumed major precipitation event, or 3) debris brought onto the street and deposited during the precipitation event. A major precipitation event is identified as at least one-half (½) inch or more of rainfall. The simulation parameters in STORM account for the residuals left on the street from the first two cases, but does not account for the possibility of any debris being washed onto the street from the surrounding land surface. The reintroduction of debris onto the street during precipitation may be significant. It was found during a study of debris accumulation in Chicago that there was a high residual loading of debris remaining on the streets after a significant rainstorm event. In some cases, the residual loading was even greater than the street loading immediately prior to the precipitation event (1).

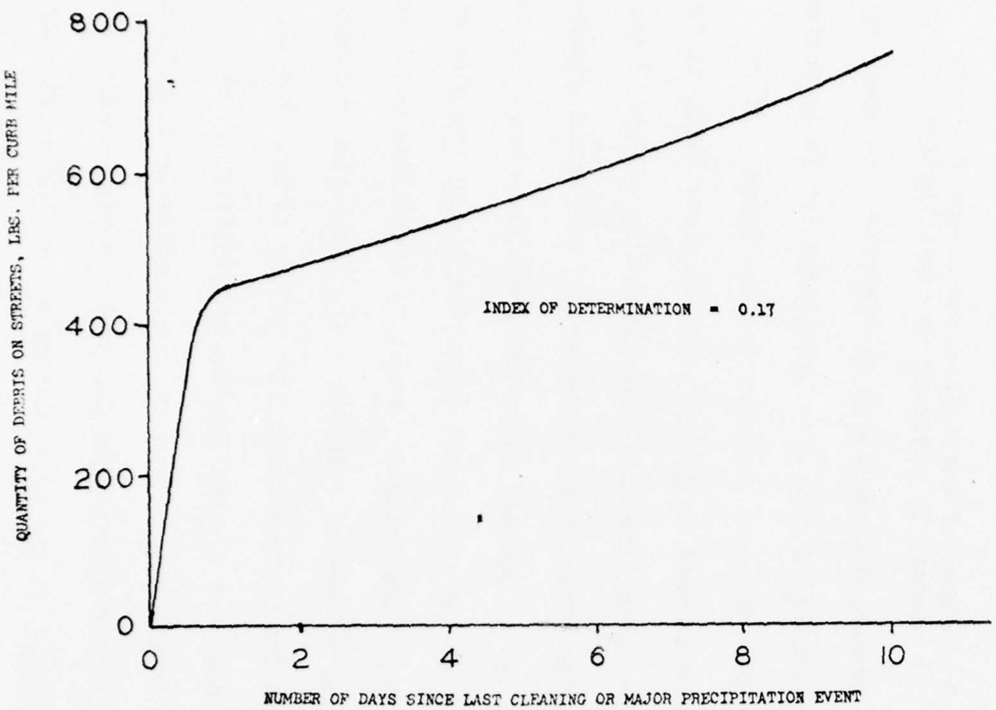

FIGURE 6

BEST "FIT" CURVE FOR STREET DEBRIS ACCUMULATION IN RESIDENTIAL LAND USE AREAS

Source: Reference 13

For the case where debris is assumed to accumulate linearly over time, as in STORM, it can be shown mathematically that for any given historic period, there is some average accumulation of debris on the streets immediately prior to precipitation. The average accumulation is dependent upon 1) the frequency and efficiency of street cleaning, and 2) the intensity, duration, and frequency of precipitation in the area. The first is input as controlled variables in STORM. In model application, the latter, for a given evaluation period, can be replaced by an average precipitation event recurring at equal time increments throughout the evaluated historic period.

The average annual summary data in the STORM output was used to compute the impervious area runoff, R_I, for the average precipitation event at Omaha, Nebraska. The evaluation period was years 1949 through 1973. Hourly precipitation recorded at Eppley Airfield, Omaha, Nebraska was used as input data for the model. The average impervious runoff event determined by this analysis is shown on Plate 10. If equation 6, Section II is modified slightly by setting Pp=1 for the first hour of runoff, computing MUp for each hour of runoff, and summing over the time period of runoff, the total debris removal fraction for this average precipitation event can be determined. The debris removal fraction for Omaha was:

$$MUp^* = 0.465\ Pp^* \qquad (9)$$

The superscript, *, is used to denote an average value. The value for MUp* can be computed from STORM output and the equations:

$$MU^{*}bod = (TLbod - 0.10TLsus - 0.02TLset)/TAE \quad (10a)$$

$$MU^{*}nit = (TLnit - 0.045TLsus - 0.01TLset)/TAE \quad (10b)$$

$$MU^{*}po4 = (TLpo4 - 0.0045TLsus - 0.001TLset)/TAE \quad (10c)$$

where

TL = Total annual computed load for the subscript pollutant.

TAE = Total annual number of computed runoff events.

A value for MUp* cannot be computed directly from the suspended and settleable solids load because of the non-linear availability factor, Ap. The average pounds of each pollutant on the street, Pp*, immediately prior to the precipitation event can then be determined from equation 9. If equation 4, Section II is modified, it can be shown that the pounds of each pollutant on the street can be redefined as:

$$NDp^{*} = Pp^{*}/FpDD_L \quad (11)$$

where

NDp^{*} = Equivalent number of days of pollutant accumulation on the street at the start of the average precipitation event.

Fp = Pound of pollutant p per pound of dust and dirt (Input value).

DD_L = Daily rate of dust and debris accumulation on the street (Input value).

Theoretically

$$ND^{*}bod = ND^{*}nit = ND^{*}po4 = ND^{*} \quad (12)$$

where

ND^{*} = Average number of days of pollutant accumulation on the street at the start of precipitation.

In actuality, they are not equal because of round-off errors during program computations for each individual runoff event. An average value for the three determinations was used for ND^{*}. As stated previously, the computed ND^{*} is also dependent upon street sweeping frequency and efficiency. By holding the efficiency factor constant and varying the frequency of sweeping, a curve can be developed showing the relative effect various sweeper frequencies would have had on the histogram of debris accumulation on the street. The resultant curve developed for Omaha is shown on Plate 11. A sweeper efficiency of 50 percent was used in the development of this curve. As shown, this curve is asymtotic and approaches a maximum at approximately 14 days of accumulation. This curve, in effect, indicates that even with only a minimal amount of street sweeping, the frequency of occurrence and intensity of precipitation around Omaha has been such that the average quantity of debris on the street would be somewhat less than what would be expected to deposit over a 14-day period. Weekly street sweeping would reduce the average quantity of debris on the street to 5.5 accumulation days.

This derived curve was used to compute linear accumulation rates for the quantities of debris measured on the streets in this study. It was assumed that both the quantity of debris on the street and the accumulation of debris during the study period was typical of historic trends. This may or may not be true, because of the dry weather experienced during the first half of the study period. The effect of sweeper efficiency was disregarded, because the results of the sensitivity analysis shown on Figure 3 indicate that the probable change in debris accumulation would be less than 5 percent for the determined efficiencies of 33 and 59 percent for the "old" and "new" residential sectors, respectively.

d. Accumulation Rates of Street Debris. Three methods of analysis, all based on the preceding derivations, were used to make separable determinations of debris accumulation rates for the residential study sectors. These methods of analysis were:

1. Determination of Accumulation Rate from First Mechanical Street Sweeping. From discussions with officials from the City of Omaha, Nebraska, it was determined that the normal sweeping frequency in residential sectors is approximately 45 days. On this basis, it was assumed for this study that the amount of debris on the street immediately prior to the first measured street sweeping was equivalent to 12.5 days of debris accumulation. The accumulation period was determined from Plate 11 using an abscissa value of 45 days. The accumulation rate of the debris was then determined by the equation:

$$dd_L = \frac{TD_1}{52.8E\ ND^*} \qquad (13)$$

where

dd_L = Daily accumulation of ovendry debris in pounds per day per 100 feet of curb.

TD_1 = Total ovendry pounds of debris collected by sweeper during first sweeping per curb mile swept.

E = Estimated sweeper efficiency.

ND^* = Average number of days accumulation of debris on the street based on historic precipitation and specified sweeper frequency (for this instance, 45 days).

2. Determination of Accumulation Rate From All Mechanical Street Sweepings. It was assumed in this analysis that the quantity of debris on the street immediately prior to the sweeping was equivalent to the accumulation at ND^*. Since the sweeping interval was approximately 15 days, ND^* was assumed to be 9 days. To determine the daily accumulation rate, dd_L, for the study period, accumulation rates were computed separately for 1) the debris remaining on the street after sweeping and 2) the debris collected by the street sweeper. For the first determination, the average quantity of debris remaining on the street after sweeping was initially computed using the equation:

$$\bar{R} = \left(\sum_{i=1}^{n} TDi\right)(1-E/nE) \qquad (14)$$

where

$\bar{R}$ = Average ovendry pounds of debris remaining on the street after cleaning in pounds per curb mile.

n = Total number of times sector was swept during the study period.

TDi = Total ovendry sweeper accumulation for sweeping i in pounds per curb mile.

E = Sweeper efficiency.

The accumulation rate for this residual, $\bar{R}^*$, was then determined by the equation:

$$\bar{R}^* = \bar{R}/52.8\ ND^* \qquad (15)$$

where $\bar{R}^*$ is in units of pounds accumulated per day per 100 feet of street curb swept.

For the second determination, the daily accumulation rate for the debris removed by the sweeper was described by the equation:

$$\overline{DR} = \sum_{i=2}^{n} TDi + \frac{((1=E/E)(TD_n - TDi))}{52.8D} \qquad (16)$$

where

$\overline{DR}$ = Average daily accumulation of debris in pounds per curb mile per day.

D = Number of days between initial and final street sweeping.

Summing the two, the daily accumulation rate was determined as:

$$dd_L = \bar{R}^* + \overline{DR} \qquad (17)$$

3. Determination of Accumulation Rate From Hand-Sweeping. It was assumed in this analysis that each hand-sweeping sample was a measure of the debris accumulation at ND^*. Since these samples were all collected during the approximate 15-day sweeping interval, ND^* was again assumed to be approximately 9 days. The daily accumulation rate was determined by the equation:

$$dd_L = \overline{HD}/52.8ND^* \qquad (18)$$

where

$\overline{HD}$ = Weighted average ovendry pounds of debris on the street as determined from "hand-sweeping" samples in pounds per curb mile.

The daily debris accumulation rates for each residential sector are summarized in Table 10. An arithmetic average of the three determinations was assumed to be the accumulation rate for street debris within each sector.

The average accumulation rates for the two aged groupings were determined to be 1.97 and 0.38 pounds per day per 100 feet of street curb for the "old" and "new" residential sectors, respectively.

TABLE 10

COMPUTED DAILY ACCUMULATION OF DEBRIS FOR RESIDENTIAL STUDY SECTORS IN POUNDS PER DAY PER 100 CURB FEET

Method of Determination	Accumulation for Residential Sector							
	CC-8	SD-4	BD-6	WB-7	NB-1	BA-1	MB-2	MC-2
1	3.98	1.18	3.23	1.18	0.98	0.62	0.43	0.29
2	3.91	0.72	2.29	0.70	0.50	0.22	0.19	0.08
3	3.49	0.80	1.45	0.70	0.27	0.59	0.14	0.25
Average	3.79	0.90	2.32	0.86	0.58	0.48	0.25	0.21
Composited Avg.	1.97				0.38			

Methods 1 and 2 were utilized to determine the accumulation rates in the commercial sectors. (No "hand-sweeping" samples were taken in these sectors.) The computed results are 4.75 and 0.83 pounds per day per 100 feet of curb for sectors BB-1 and Center Street, respectively. The results determined for sector BB-1 are greatly influenced by the large amount of debris collected on the first sweeping.

e. Accumulation Rate for Debris Fraction Removed by Runoff. In assessing the pollutional aspects of debris on the street, it was assumed in the Chicago study that only the debris and the associated constituents passing through a 1/8 inch diameter sieve would be included as part of the runoff pollution load (1). The equivalent particle size is approximately 3 mm. Particles of this size are classified as very fine gravel. The studies by the Environmental Protection Agency determined that some particles greater than 2 mm are removed from the street during runoff by either saltation or suspension movement, but essentially all particles of this size are retained in the storm sewer catch basin (13). Therefore, only the debris finer than 2 mm in diameter was considered to contribute to the runoff pollution load in this study. The composited sieve analyses on Plate 6 show that the fractional difference between the particle sizes used in the Chicago study and this study is less than 6 percent.

Approximately 72 percent of the total street debris was found to be less than or equal to 2 mm in diameter. Therefore, the adjusted accumulation rate for the debris size fractions assumed to be removed by runoff would be 1.42 and 0.28 pounds per day per 100 feet of street curb for the "old" and "new" sectors, respectively.

f. Adjustment of Accumulation Rate for Unmeasured Debris Loading on Street. The "hand-sweeping" data collected for this study measured only the street debris deposited within four feet of the curb. The studies conducted by the Environmental Protection Agency found that approximately 97 percent of the total street debris is contained within this portion of the street (13). However, to compute the total street loading, the accumulation rate was adjusted to account for the unmeasured portion. It is assumed that the distribution of the material is similar to that of the collected debris. With this adjustment, the total accumulation rate for the pollutional debris ($\leq$ 2 mm) is 1.46 and 0.29 for "old" and "new" residential sectors, respectively.

g. Quality Input Values for STORM. Based on the results and interpretations of this study data, the quality input parameters for operation of STORM were developed. The mass emission of pollution computed by the model during a precipitation event consists of a summated value for the pollution associated with the soluble,

suspended, and settleable solid fractions. As stated previously, the soluble pollution load, per se, was not measured in this study. However, since the measured laboratory results include the soluble fraction, a warranted value for the soluble pollution loading can be estimated. A soluble value for each pollution parameter was obtained from the extrapolated curves on Plate 7. The data was extrapolated only to a particle size of 5 microns, because of the increasing uncertainty that would be introduced in the analysis by extrapolating to a finer particle size. This point was considered to be the effective filtration diameter for separating soluble and insoluble particulates. The actual particle diameter separating soluble-insoluble classifications, although not specifically defined, is approximately one order of magnitude finer. This interpretive analysis was considered valid, because the pollution curves are accumulative with particle size and errors become self-correcting with increasing particle size. The input values for STORM for the residential land use classification in Omaha, Nebraska is included in Table 11.

The soluble pollutant "strength," as determined for Omaha, is somewhat less than the values measured in the Chicago study, It is speculated that at least some of the difference is accounted for by differences in sample preparation. All of the debris passing the

1/8 inch diameter sieve in the Chicago study was pulverized prior to filtering for analysis (1). This action would tend to divide the dried organic matter into very fine particulates. Thus, the measured soluble pollution loading would be increased. The organic material was not pulverized in this study.

The basic water quality equations used in the model (equations 7c, 7d, and 7e) were also recomputed based on study findings. The recomputed equations are:

$$MUbod(t) = Pbod(t)\ EXPT + 0.46\ MUsus + 0.04\ MUsettl \quad (19a)$$

$$MUnit(t) = Pnit(t)\ EXPT + 0.03\ MUsus + 0.003\ MUsettl \quad (19b)$$

$$MUpo4(t) = Ppo4(t)\ EXPT + 0.008\ MUsus + 0.003\ MUsettl \quad (19c)$$

The original equations are fixed in the STORM program. However, it was found that the runoff pollution loadings computed by the model could be separated by particle size fraction and adjusted to account for the differences between the original and these recomputed equations. Results from the use of the derived input values in the model are discussed in the next section.

TABLE 11

COMPUTED QUALITY INPUT VALUES FOR "STORM"

	Residential Land Use		
	"Old"	"New"	Combined
Accumulation Rate for Pollutional Debris (lbs/day/100' curb)	1.46	0.29	0.88
Pounds of Pollutant Per 100 Pounds of Pollutional Debris			
Suspended Solids		0.33	
Settleable Solids		17.10	
COD		0.29	
BOD_5		0.26	
Kjel. N		0.013	
Ext. PO_4		0.012	
Lead		0.0012	
Zinc		0.0005	
Chromium		0.00002	
Nickel		0.00004	

SECTION V

URBAN RUNOFF POLLUTION

SECTION V - URBAN RUNOFF POLLUTION

5.1. General.

The origin and quantification of the sources contributing pollution to the general degradated water quality of urban runoff has never truly been identified. It is generally assumed that streets are a principal source, because of the heavy visual accumulation of debris commonly found on streets. The conclusions of the street debris analysis developed by this study were used to evaluate the relative importance of streets in contributing pollution to runoff. The time step computational elements in STORM provided the means to compute the contribution from the street. The possible role of other sources are also identified and discussed in the following comments.

5.2. Runoff Pollution Originating From the Street.

The quality subroutine in STORM was used to summarize the time history washoff of pollution from the street. For a given precipitation record and input values for sweeper frequency, sweeper efficiency, and the washoff decay coefficient, K, the amount of debris washed off the street, as computed by the model, is actually a fraction of the total possible accumulation. This fraction, for the same precipitation record, remains constant and independent of the specified accumulation rate and pollutant "strength." If the historic record is summarized on an annual basis, the fraction of the total accumulation can be identified as an average annual

number of days of debris accumulation removed by precipitation. Because of the availability factor, Ap, associated with the suspended and settleable solid equations, the average days of washoff is different for the soluble, suspended, and settleable solid fractions. The computed solids removal, assuming Omaha criteria, is plotted on Plate 12 for each of the three size fractions for a variable sweeping frequency interval up to 100 days. The 1949 through 1973 precipitation record from Eppley Airfield, a sweeper efficiency of 50 percent, and a washoff decay constant of 2.0 was used in deriving these curves. It is possible to use these curves in lieu of running the program to compute the average annual mass emission load for any accumulation rate or pollutant "strength." In addition, by using the curves, the pollutant concentration that remains transfixed to the suspended and settleable solid particulates can be varied. These values are constants in STORM (equations 7c, d and e, Section II).

The program input values derived from evaluation of the collected data in this study were used to compute the average annual runoff pollution load from streets. The resultant runoff loadings for the two residential age classifications and the combined average are included in Table 12. The total runoff load has been subdivided into each of the three transport categories; i.e., soluble, suspended, and settleable. The sweeping frequency

is assumed to be 45 days. The total pollution load, as determined by this method, is comparable to results obtained using Chicago input data. The average equivalent pollutant concentration in the runoff is summarized in Table 13. This table also includes a comparison of the determined concentrations to average concentrations assumed for residential runoff quality in the Omaha Metro Study area. The latter were developed from a review of the literature.

TABLE 12

COMPUTED AVERAGE ANNUAL MASS EMISSION OF POLLUTANTS
FROM RESIDENTIAL STREETS IN OMAHA, NEBRASKA

PER MILE OF STREET

Quality Parameter	Soluble			Suspended			Settleable			Total		
	Old	New	Comb	Old	New	Comb	Old	New	Comb	Old	New	Comb
Total Solids	363.6	70.8	214.8	106.8	20.8	63.2	4520.0	880.0	2712.0	4988.0	971.2	2948.0
Volatile Solids	98.4	19.2	58.0	98.8	19.2	58.4	578.4	112.4	341.6	776.0	150.8	458.0
Chemical Oxygen Demand	126.4	24.4	74.0	127.6	24.8	75.2	741.0	139.2	422.0	968.0	188.4	571.6
Biochemical Oxygen Demand	111.2	21.6	65.6	49.6	9.6	29.2	171.6	33.6	101.6	332.4	64.8	196.4
Kjeldahl Nitrogen	5.6	1.1	3.3	3.3	0.6	2.0	11.8	2.3	7.0	20.6	4.0	12.2
Extractable Phosphate	5.1	1.0	3.0	0.8	0.2	0.5	14.9	2.9	8.8	20.9	4.1	12.4
Lead $X10^{-2}$	52.0	8.0	32.0	8.0	2.0	5.0	172.0	32.0	1.0	232.0	45.0	136.0
Zinc $X10^{-2}$	20.0	4.0	12.0	3.2	0.6	1.6	90.4	17.6	53.2	114.0	22.0	67.0
Chromium $X10^{-4}$	100.0	20.0	60.0	16.0	3.0	8.0	540.0	100.0	320.0	660.0	130.0	390.0
Nickel $X10^{-4}$	180.0	40.0	110.0	20.0	3.0	8.0	540.0	100.0	320.0	740.0	140.0	440.0

PER ACRE OF LAND *

Quality Parameter	Soluble			Suspended			Settleable			Total		
	Old	New	Comb	Old	New	Comb	Old	New	Comb	Old	New	Comb
Total Solids	10.3	2.0	6.1	3.0	0.6	1.8	128.4	25.0	75.8	141.8	27.6	83.7
Volatile Solids	2.8	0.5	1.6	2.8	0.55	1.66	16.4	3.2	9.7	22.0	4.3	13.0
Chemical Oxygen Demand	3.6	0.7	2.1	3.6	0.70	2.14	20.3	4.0	12.0	27.5	5.3	16.2
Biochemical Oxygen Demand	3.2	0.6	1.9	1.4	0.27	0.83	4.9	1.0	2.9	9.4	1.8	5.6
Kjeldahl Nitrogen	0.2	0.0	0.1	0.09	0.02	0.06	0.3	0.1	0.2	0.6	0.1	0.4
Extractable Phosphate	0.1	0.0	0.1	0.02	0.00	0.01	0.4	0.1	0.2	0.6	0.1	0.4
Lead $X10^{-2}$	1.4	0.3	0.9	0.2	0.05	0.14	4.8	1.0	2.9	6.6	1.3	3.9
Zinc $X10^{-2}$	0.6	0.1	0.3	0.9	0.02	0.06	2.6	0.5	1.5	3.2	0.6	1.9
Chromium $X10^{-4}$	2.9	0.6	1.7	0.4	0.1	0.3	15.0	3.0	9.0	19.0	4.0	11.0
Nickel $X10^{-4}$	5.2	1.0	3.1	0.4	0.1	0.3	15.0	3.0	9.0	21.0	4.0	12.0

* Street density of 300 curb feet per acre.

TABLE 13

AVERAGE CONCENTRATION OF RUNOFF FROM
RESIDENTIAL STREETS AND TOTAL LAND AREA

	Average Annual Computed Runoff Concentration: Street Runoff			Total Land Area Runoff 1/			Assumed Runoff Concentrations 2/
	"Old"	"New"	Comb.	"Old"	"New"	Comb.	
Total Solids 3/	480.2	93.5	283.5	95.2	18.5	56.2	340
Volatile Solids	74.5	14.6	44.0	14.8	2.9	8.7	
Chemical Oxygen Demand	93.1	18.1	54.9	18.5	3.6	10.9	160
Biochemical Oxygen Demand	31.8	6.2	19.0	6.3	1.2	3.8	22
Kjeldahl Nitrogen	2.00	0.37	1.18	0.40	0.07	0.24	2.9 4/
Extractable Phosphate	2.00	0.41	1.18	0.40	0.08	0.24	2.0
Lead	0.22	0.044	0.132	0.044	0.009	0.026	
Zinc	0.108	0.020	0.064	0.021	0.004	0.013	
Chromium	0.0064	0.0013	0.0037	0.0012	0.0002	0.0007	
Nickel	0.0071	0.0013	0.0040	0.0014	0.0002	0.0008	

1/Assumed street density of 300 curb feet per acre and 30 percent imperviousness.

2/Values assumed for Omaha Metro Study. Based on measured concentrations published in the literature for other cities.

3/All values reported in mg/l.

4/Includes nitrates which were not included in this study.

The average concentration for the major pollutants are only 20 percent or less of the average runoff concentrations generally measured in residential land use areas. Perhaps more pollution originates from the street than was determined by this analysis. However, it can also be shown that if each of the 45.12 average annual runoff events was to remove the determined average accumulation of solids and pollutants associated with particles 1 mm and finer, the average runoff concentration would still remain at a level of 80 percent or less of average measured values. The major counter argument to this claim is that less than 10 percent of this pollutant load would be soluble. Generally, about one-half (½) of the measured runoff pollution is associated with the soluble particulate classification.

5.3. Contribution of Pollution From Other Sources. Based on these conclusions, other sources must contribute significant pollution loads to urban runoff. Other such major identifiable sources would include:

1. Impervious surfaces other than streets;
2. Pervious areas;
3. Catch basins and the conveyance network; and
4. The atmosphere.

Little, if any, information is available, at present, to quantify the pollution contribution from these other sources. However, based on a preliminary assessment, much of the additional pollution

load may originate from impervious surfaces other than streets. This conclusion is supported by the following analysis.

5.4. Pollution From Impervious Surfaces Other Than Streets. During the period of October 1965 through March 1968, the Omaha-Douglas County Health Department determined monthly dustfall rates from several locations within and around the City of Omaha. The results of these studies are summarized in Table 14.

TABLE 14

DUSTFALL RATE FOR OMAHA, NEBRASKA

Month	Solids Collection Rate, Tons/sq. mi./mo. Insoluble High	Low	Median	Rural	Soluble High	Low	Median	Rural
January	52.3	1.1	9.6	3.6	16.5	0.9	5.5	1.9
February	38.0	1.4	13.0	4.6	10.5	1.6	5.4	1.5
March	54.2	4.1	16.6	7.0	9.4	2.0	5.0	2.6
April	88.6	7.1	32.5	15.8	46.2	1.8	9.0	4.0
May	125.1	6.6	26.8	16.5	12.0	2.1	5.1	3.0
June	91.5	10.4	25.5	17.7	22.1	3.5	7.6	5.9
July	117.4	0.9	19.3	8.9	15.9	1.8	7.7	4.7
August	47.3	0.4	16.3	8.0	14.1	1.5	6.0	4.6
September	38.9	1.6	19.4	10.3	12.2	2.2	6.8	4.0
October	66.8	4.8	16.9	5.9	23.6	2.1	6.2	7.7
November	55.7	3.0	13.2	4.0	9.7	1.0	4.9	3.3
December	44.8	1.7	10.6	3.5	46.3	2.2	10.6	23.1
Total Annual			219.7	105.8			79.8	66.3
April-September			139.8	77.2			42.2	26.2
lbs x 10^{-5}/ft^2/day (Total Annual)			4.31	2.1			1.56	1.30
lbs x 10^{-5}/ft^2/day (Total Annual)			5.47	3.0			1.64	1.00

Source: Data collected by Omaha-Douglas County Health Department, October 1965 - March 1968.

Quality parameters associated with these dustfall particles were not measured by the Health Department. However, a study conducted in Seattle, Washington during the summer of 1966 indicates that there is a quality element associated with this dustfall and that the quantity and quality of the dustfall is somewhat dependent upon the local land use activity (3). If so, much of the measured dustfall could have the same origin as street debris or, in fact, include some particulates removed from the street by traffic, wind, and cleaning. It was, therefore, concluded that the quality of the dustfall could possibly be quite similar to the measured quality of the finer street debris size fractions. The major quality parameters were estimated for dustfall based on the data evaluations in Section IV. The maximum dustfall particle size was assumed to be 40 microns (3). These estimates are compared to reported Seattle findings in Table 15.

TABLE 15

DUSTFALL DEPOSITION RATES FOR OMAHA, NEBRASKA AND SEATTLE, WASHINGTON IN POUNDS PER SQUARE FOOT PER DAY

Constituent	Deposition Rate					
	Omaha			Seattle*		
	Soluble	Insoluble	Total	Soluble	Insoluble	Total
Total Solids $\times 10^{-5}$	1.56	4.31	5.87	2.82	2.94	5.76
Volatile Solids $\times 10^{-5}$	0.41	0.47	0.88	1.34	1.06	2.40
BOD $\times 10^{-5}$	0.46	0.20	0.66	-	-	-
Kjeldahl Nit. $\times 10^{-5}$	0.022	0.014	0.036	-	-	-
Nitrates $\times 10^{-5}$	-	-	-	0.032	-	0.022
Phosphate $\times 10^{-5}$	0.020	0.020	0.040	0.006	-	0.006

*Reference 3.

The contribution of dustfall in Omaha to urban runoff pollution was determined based on the deposition rates included in Table 15. This analysis assumed that 100 percent of the dustfall, collecting on impervious surfaces other than streets, would be removed by runoff, but no dustfall was assumed to be removed by runoff from pervious areas. These estimated total annual runoff pollution loads for various percentages of areal imperviousness are included in Table 16 for the quality parameters of Total Solids, BOD_5, Kjeldahl Nitrogen, and Extractable Phosphate. This table also includes the previously determined annual pollution load for residential streets (Table 12) and the average runoff concentration for the combined total runoff loads. Annual runoff volumes were computed with STORM. The resultant average concentrations were still less than the concentrations assumed for residential runoff (Table 13). Comparative concentrations range from 37 percent of assumed measured runoff concentrations for total nitrogen to about 88 percent for BOD_5. The nitrogen concentrations were expected to be low, because the nitrate fraction was not included in the analysis. Nevertheless, the results tend to indicate that dustfall may be a very significant source of pollution in urban runoff. Since most of the data used in these determinations was basically synthetic, additional research will be needed to validate or qualify the importance of dustfall in urban runoff pollution.

TABLE 16

ESTIMATED AVERAGE ANNUAL POLLUTION LOAD FROM DUSTFALL
ON IMPERVIOUS SURFACES AND DEBRIS COLLECTING ON STREETS

Per cent Imp. (%)	Street Length (Ft/Ac)	Other Imper. Area (Ft²)	Avg. Annual Runoff Inches	Total Solids Street Sol. lbs/yr	Total Solids Street Insol lbs/yr	Total Solids Other Imp. Sol. lbs/yr	Total Solids Other Imp. Insol lbs/yr	Avg. Conc. mg/l	Biochemical Oxygen Demand Street Sol. lbs/yr	BOD Street Insol. lbs/yr	BOD Other Imp. Sol. lbs/yr	BOD Other Imp. Insol. lbs/yr	Avg. Conc. mg/l	Kjeldahl Nitrogen Street Sol. lbs/yr	KN Street Insol. lbs/yr	KN Other Imp. Sol. lbs/yr	KN Other Imp. Insol lbs/yr	Avg. Conc. mg/l	Extractable Phosphate Street Sol. lbs/yr	EP Street Insol. lbs/yr	EP Other Imp. Sol. lbs/yr	EP Other Imp. Insol. lbs/yr	Avg. Conc. mg/l
8.2	300	0	3.71	6.1	77.6	0	0	100	1.87	3.73	0	0	6.7	0.09	0.26	0	0	0.42	0.09	0.26	0	0	0.42
20	300	5112	5.26	6.1	77.6	29.1	80.4	162	1.87	3.73	8.6	3.7	15.0	0.09	0.26	0.41	0.26	0.86	0.09	0.26	0.37	0.19	0.76
25	300	7290	5.92	6.1	77.6	41.5	114.7	179	1.87	3.73	12.2	5.3	17.3	0.09	0.26	0.58	0.37	0.98	0.09	0.26	0.53	0.27	0.86
30	300	9486	6.58	6.1	77.6	53.9	148.9	192	1.87	3.73	15.9	6.9	19.1	0.09	0.26	0.76	0.48	1.07	0.09	0.26	0.69	0.34	0.94
35	300	11646	7.24	6.1	77.6	66.3	183.2	203	1.87	3.73	19.6	8.5	20.5	0.09	0.26	0.93	0.60	1.15	0.09	0.26	0.85	0.43	0.99
40	300	13824	7.90	6.1	77.6	78.7	217.5	213	1.87	3.73	23.2	10.1	21.8	0.09	0.26	1.11	0.71	1.21	0.09	0.26	1.00	0.50	1.04
45	300	16002	8.55	6.1	77.6	91.1	251.7	220	1.87	3.73	26.9	11.7	22.8	0.09	0.26	1.28	0.82	1.27	0.09	0.26	1.17	0.58	1.09
50	300	18180	9.21	6.1	77.6	103.5	286.0	227	1.87	3.73	30.5	13.3	23.7	0.09	0.26	1.46	0.93	1.31	0.09	0.26	1.33	0.66	1.12
60	300	22536	10.53	6.1	77.6	128.3	354.5	238	1.87	3.73	37.8	16.4	25.1	0.09	0.26	1.80	1.15	1.39	0.09	0.26	1.64	0.82	1.18
70	300	26792	11.84	6.1	77.6	153.1	423.1	246	1.87	3.73	45.2	19.6	26.3	0.09	0.26	2.16	1.37	1.45	0.09	0.26	1.96	0.98	1.23
80	300	31248	13.16	6.1	77.6	177.9	491.6	253	1.87	3.73	52.5	22.8	27.2	0.09	0.26	2.51	1.60	1.50	0.09	0.26	2.28	1.14	1.27
90	300	35604	14.47	6.1	77.6	202.7	560.1	259	1.87	3.73	59.8	26.0	27.9	0.09	0.26	2.86	1.82	1.54	0.09	0.26	2.60	1.30	1.30
100	300	39960	15.79	6.1	77.6	227.5	628.6	263	1.87	3.73	67.0	29.2	28.5	0.09	0.26	3.21	2.04	1.57	0.09	0.26	2.92	1.46	1.32

SECTION VI

NON-STRUCTURAL METHODS OF IMPROVING URBAN RUNOFF QUALITY AND QUANTITY

SECTION VI

NON-STRUCTURAL METHODS OF IMPROVING URBAN RUNOFF QUALITY AND QUANTITY

6.1. General.

Non-structural methods for improving urban runoff quality are defined in this report as any method of land use planning, regulation, or maintenance which may reduce the mass emission rate and load of pollutants from an urban area, but is not an integral part of any physical wastewater management system. Means and methods of reducing pollution from urban construction activities is not discussed. Several reports are available in the literature which discuss this subject in detail. Two Environmental Protection Agency reports are included in the references to this report (11 and 12). The scope and completeness of this section is very limited, because of all of the significant sources of urban runoff pollutants have not been identified, measured, and evaluated. Much of the discussion is centered around observations and measurements obtained from the data acquisition program for this study and use of the historical precipitation analysis capability of STORM. The subjects discussed include:

a. Effectiveness and optimal scheduling of street sweepers for reducing urban pollution,

b. Effectiveness of planning and controlling interior drainage to reduce urban runoff quantity and pollution, and

c. Effects of local land use development, practices, and management on the collection or urban debris.

6.2. Effectiveness and Optimal Scheduling of Street Sweepers.

The effectiveness of a well maintained and operated street sweeping program for pollution control is difficult to evaluate. Based on the analyses in this report, only about 20 percent of the urban runoff pollution load in residential areas originates from the streets. This pollution loading is mainly from the finer debris residing on the street at the time of runoff. However, streets are possibly the initial source of pollutional debris removed from other sources during runoff. For example, two such sources could be: 1) fine dust blown off of the street onto the surrounding land surfaces during dry periods, and 2) organic and other debris deposited in catch basins during preceding runoff events or by other methods such as traffic and street flushers. As such, any full evaluation of the effectiveness of a street sweeping program in reducing urban runoff pollution will require a more complete evaluation and understanding of urban runoff pollution sources and the origin-removal cycle. It is, however, assumed in this study that an effective street sweeping program can materially reduce urban runoff pollution.

The effectiveness of a street sweeping program, as considered in this report, is measured by the degree of reduction in street

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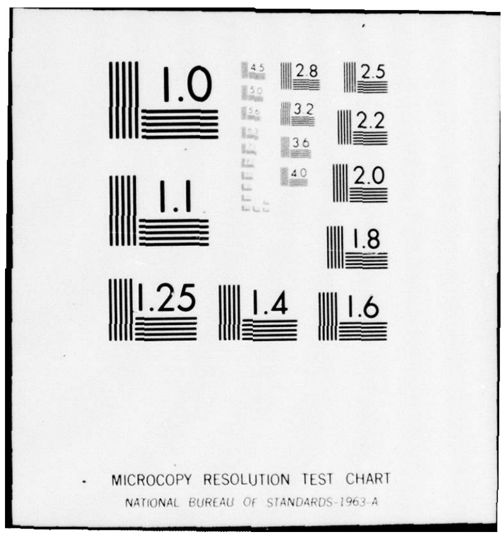
1.0
1.1
1.25
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

runoff pollution. If it is assumed that the debris accumulates linearly with time, and that there are only two major removal mechanisms, runoff and sweeping, the effectiveness of street sweeping in reducing runoff pollution can be approximated. The time continuous computational element in STORM provides the comparative basis to evaluate the interaction of these debris removal mechanisms throughout a historical analysis period. This evaluation was discussed previously in this report. The resultant average annual washoff of debris versus sweeping frequency curves for the three pollution classifications; i.e., soluble, suspended, and settleable, are shown on Plate 12. The data used as input in the model included the 1949 through 1973 hourly precipitation record at Eppley Airfield, an assumed sweeper efficiency of 50 percent, and a washoff decay coefficient of 2.0.

Based on the determinations from the preceding analysis, sweeper effectiveness curves were developed. To simplify the evaluation, it was assumed that all size fractions of debris were described by the "soluble" curve on Plate 12. The other two curves on this Plate are reduced by the non-linear availability factor, Ap (Equations 7a, b, Section II). Sweeper effectiveness was defined as the fractional reduction in computed annual debris runoff load relative to total annual debris runoff. A sweeping frequency

of 100 days was established as the total annual debris runoff load. Resultant sweeper effectiveness curves for assumed sweeper efficiencies of 50 and 99 percent are shown on Plate 13. These curves were then used to determine the optimal sweeping frequency for Omaha.

A full optimization analysis of a street sweeping program would require detailed information on equipment, manpower requirements, operation and maintenance costs, etc. This information was not available. Therefore, this analysis only considered the optimal sweeping frequency for equipment utilization. A summary of the optimal equipment utilization analysis is included in Table 17 for the sweeper effectiveness curves plotted on Plate 13. The derived utilization curves are included on Plate 13.

It can be seen from this long-term precipitation analysis and the assumptions used in development of the curves, the optimal street sweeping frequency for Omaha is anywhere from 11 to 16 days. The utilization curves also show that for any major deviation from this sweeping frequency range, the return amount of runoff pollution reduction per unit of equipment effort becomes significantly less. In addition, an increased sweeper efficiency allows for a longer sweeping interval with less decrease in utilization. The overall reduction in street runoff pollution for a 50 percent efficient street sweeper at the optimal sweeping frequency would be about

30 to 40 percent. If equipment design changes should substantially increase sweeping efficiencies in the future, the reduction in street runoff pollution might increase to around 45 to 60 percent.

TABLE 17

EQUIPMENT OPTIMIZATION ANALYSIS FOR REDUCING RUNOFF POLLUTION FROM STREETS

Reduction in Avg. Annual Street Pollution	Sweeper Frequency (50%E) days	Sweeper Frequency (100%E) days	Relative Frequency 1/ (50%)	Relative Frequency 1/ (100%)	Sweeper Utilization 2/ (50%)	Sweeper Utilization 2/ (100%)
0	100	100	1.000	1.000	-	-
10	35	56	2.857	1.786	0.72	0.82
20	22	32	4.545	3.125	0.92	0.93
30	16	22.0	6.250	4.651	0.99	0.96
40	12	17.0	8.333	5.888	1.00	0.99
50	9	13.7	11.111	7.407	0.94	1.00
60	7	10.5	14.286	9.524	0.87	0.92
70	5	8.0	20.000	12.500	0.73	0.82
80	3	5	33.333	20.000	0.50	0.58
90	1½	2½	66.666	40.000	0.20	0.33

1/100 days/Sweeper Frequency.
2/Percent reduction/Relative Frequency/optimum value.

6.3. Effectiveness of Planning and Controlling Interior Drainage.

The drainage of impervious runoff over pervious land areas may effectively reduce the total runoff pollution load from an urban area. Two primary mechanisms would be involved in the reduction. These are: 1) reduction of the runoff volume and, consequently, the pollution load; and 2) removal of particulates from the runoff waters, primarily via physical processes such as sedimentation and filtration.

From an analysis of the long-term precipitation record in Omaha (1949 through 1973) with STORM, the average hourly precipitation intensity of rainfall was determined. The results indicate that, on the average, the saturated infiltration rate for the soils in the study area greatly exceeds rainfall intensity. Thus, some additional infiltration capacity is normally available to reduce the runoff volume from impervious surfaces. If it is assumed that the impervious runoff is drained uniformly over the available pervious lands in the urban area during a precipitation event, it can be shown that the effective precipitation intensity rate on the pervious areas would be:

$$P_{PA} = P + \frac{F_I \, C_I}{F_P} \, P \qquad (19)$$

Where

P_{PA} = Adjusted precipitation intensity for pervious land area in inches per hour.

P = Precipitation intensity of storm in inches per hour.

F_I = Fraction of urban area that is impervious.

C_I = Runoff coefficient for impervious area.

F_P = Fraction of urban area that is pervious.

By evaluating the hourly historic precipitation record, any resultant reduction in runoff volume can be evaluated.

A modified version of the runoff routine in STORM was used to make this analysis. The modification consisted of replacing the available depression storage value, F, in equation 1 by the average saturated infiltration rate for the soils in Omaha. This was done quite easily in the model by inputting the 24-hour saturated infiltration rate, rather than the daily evaporation rate. An infiltration rate of 0.3 inches per hour was used. The input value for the maximum available depression storage, D, was changed to include both the maximum available depression storage for the pervious lands and the assumed first-hour infiltration rate. The results indicate a total runoff quantity reduction of 25, 28, and 30 percent for urban areas having respective impervious surface areas of 30, 40, and 50 percent.

To assess the effectiveness of runoff reduction on a small unit basis, the results can be interpreted on the basis of percentage reduction in runoff volume versus the ratio of the area of pervious lands covered by impervious runoff to the impervious land area. The curve derived for Omaha is shown on Plate 14. The average annual reduction in the volume of impervious runoff was found to be approximately 73 percent for equal areas of pervious and impervious surfaces. These findings, as based on this analysis, were more dramatic than originally anticipated. It must be emphasized, however, that the degree of effectiveness decreases with increasing rainfall intensity, such that essentially no reduction in runoff would occur for major design storm events.

The same analysis procedure is not valid in evaluating the reduction in runoff pollution. Equivalent evaluation attempts which use the historical precipitation would require considerable modification of the quality routine in the model. For this reason, an attempt to evaluate comparable reductions in runoff pollution was not considered. It can probably be assumed that the reduction in the pollution originating from the impervious surfaces would be some factor less than the reduction in impervious runoff. However, it does appear that a detailed evaluation of this urban land management technique may be warranted particularly in view of the fact that some additional particulate debris may also be removed by

filtration and sedimentation during sheet flow over any sodded area. Studies of rural land management practices in Texas determined that the construction of grassed waterways reduced the sediment yield from the study basin by 70 percent (14). Most of this measured reduction was probably a result of the filtration and sedimentation action during flow over the grassed portion of the waterway.

6.4. Effect of Land Use Development and Management.

The results from the collection and analysis of street debris in Omaha show that the older residential land use areas had significantly greater quantities of debris on the streets than was found in the newer residential areas. The study was not sufficiently comprehensive to fully identify and quantify the causes and sources of the additional debris. However, some physical, as well as land management, factors noted by observation during data collection can be identified as adding to or reducing the quantity of debris on the street. These physical factors are summarized on Table 18. A positive value infers an increase in either the accumulation or removal rate, while a negative designation indicates a reduction. A blank denotes essentially no effect. Four removal mechanisms are considered in the evaluation.

TABLE 18
PHYSICAL FACTORS AFFECTING DEBRIS
ACCUMULATION ON STREETS

Factor	Debris Accumulation: Primary Source (1)	Debris Accumulation: Secondary Source (2)	Debris Accumulation: Other (3)	Debris Removal: Local Activity (4)	Debris Removal: Street Sweeping (5)	Debris Removal: Precipitation (6)	Debris Removal: Vehicular Traffic (7)	Reasons
Vegetative Canopy over street	(+)		(+)			(−)	(−)	(3) Activities and excretments of animals. (6) Reduction in raindrop impact. (7) Shading reduces evaporation and, consequently, a reduction in dust which can be blown off of the street by traffic.
On Street Parking		(+)			(−)	(−)	(−)	(5) Unable to sweep entire curb lane. (6) Reduces removal from raindrop impact. (7) Provides additional street buffer zone for retention of debris moved from traffic lane.
Street Repair	(−)	(−)	(−)		(+)	(+)	(+)	(2) Debris from traveling vehicles. (3) Cracks and holes become detention areas. (5) Better sweeping surface. (6) Less roughness, greater runoff velocities. (7) Faster traffic flow.
Social Economic Level	(−)		(−)	(+)	(+)			(1) Increased maintenance and care of land areas. (3) Trash and other debris. (4) Increase in local maintenance and clean-up. (5) Tax base can influence sweeping frequency.
Traffic		(+)					(+)	(2) Debris from traveling vehicles. (7) More pulverization of debris and more dust removal.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions.

a. Contribution of Street Debris to Urban Runoff Pollution. Streets probably contain, by far, the greatest quantity of naturally transported debris in an urban area. From visual appearances only, it is easy to recognize why streets have been considered the major source of urban runoff pollution. However, the results of the data evaluations and analyses conducted in this study indicate rather conclusively that street debris is probably not the major source of urban runoff pollutants. Specific study findings are discussed in the summary of this report (Section I). The following comments are primarily a prospectus of the role of street debris in the urban runoff pollution problem.

1. Street debris is composed of only a very small percentage of fine particulate matter. Approximately 99.5 percent by weight of the street debris was estimated to be larger than clay. It is speculated that the wind currents, either weather or traffic induced, that move nearly all of the debris to the curb are capable of moving the finer debris off of the street proper onto the surrounding land surface.

2. Most of the pollution load on the street is associated with the silt, sand, and larger debris fractions. Even though the pollutant concentration of the larger debris is several fold less

than the colloidal and near-colloidal particles, the voluminous percentage of the larger particulates in street debris is such that most of the total pollution load is associated with this fraction of the street debris. Thus, converse to the discussion in paragraph a, most street pollution is associated with particulates that are 1) difficult to remove from the street surface and maintain in suspension by water flow during runoff and 2) subject to considerable losses from entrapment and deposition during transport through a drainage system. The removal of these size fractions from the street is largely dependant upon the intensity and duration of the precipitation event and hydraulic characteristics of the conveyance network.

3. *The average runoff pollution contribution from the street is only a minor portion of the total runoff pollution load.* A long-term analysis of street debris accumulation and removal by street sweeping and precipitation indicates that streets contribute only about 20 percent of the total residential runoff pollution load. This conclusion is based on a 25-year analysis of precipitation frequency, intensity, and duration in Omaha, Nebraska using STORM. The water quality input values were based on determinations from the sampling program. The average total solids and BOD_5 concentrations as determined by the model were 56 mg/l and 3.8 mg/l, respectively.

4. Most of the pollution removed from the street by precipitation is associated with the insoluble particulates. Approximately

93 percent of the total solids and 67 percent of the BOD_5 loading of the street debris runoff was found to be insoluble. These percentages are based on the model determinations that the frequency and intensity of precipitation in Omaha is such that about 70 percent of the soluble street debris and about 50 percent of suspended and settleable debris is removed annually by runoff. The portion of the debris not removed by runoff is assumed to be removed from the street by street sweeping. The sweeping frequency for these determinations was 30 days. This determination was expected based on the discussions in paragraph (1) and (2) but is significant for primarily two reasons. First, much of the runoff pollution originating from the street can be removed by physical treatment systems, such as settling basins and microscreening. Secondly, the low soluble-insoluble pollution ratio further substantiates the conclusion that streets are not the major source of urban runoff pollutants. Generally, measured urban runoff pollution ratios are higher indicating a much greater percentage of soluble pollution than could originate from streets.

b. Other Study Conclusions.

1. Fallout of fine particulates on impervious surfaces, other than streets, could be a very significant source of urban runoff pollutants. Data on the quality of particulate fallout within the city of Omaha has not been measured. However, based on estimates of the quality of this fallout, it was determined that this source could possibly account for 50 to 80 percent of the pollution in urban runoff.

Of major significance is the fact that this source would be composed mainly of soluble and near soluble particulates. These fine and very fine particulates were noteably lacking in street debris. To visually exemplify this point, the average particle size and associated BOD_5 loading distribution for street debris and fallout on impervious surfaces, other than streets, is compared on Plate 15. (This plate is included in the conclusions only for clarification of the discussion.)

2. Average street debris loadings are greater in "older" residential developments than in the "newer" developments. Sufficient data was not collected in this study to fully identify the causal factors. However, some factors identified through observation which possibly affect the quantity of debris on the street include:

(a) Degree of vegetative canopy coverage over the street;

(b) Amount of on-street parking;

(c) Repair of the street;

(d) Social-economic level of development; and

(e) Amount of traffic.

3. The optimum street sweeper frequency in reducing runoff pollution from streets would be about 11 to 16 days for Omaha. This determination was based on an optimization analysis of street sweeper utilization based on determinations using STORM. The resultant reduction in street runoff pollution was about 30 to 40 percent.

4. The average annual quantity of impervious runoff can be reduced significantly by drainage of this runoff across a pervious land area. This determination was based on a long-term analysis of

precipitation in Omaha using STORM. The premise of the analysis was that the saturated infiltration capacity of the pervious soils in the area exceeds the average intensity of precipitation in Omaha. The resultant reduction in impervious runoff, based on the model determinations, was about 73 percent for drainage of an impervious drainage area across an equal area of pervious land. Some reduction in pollution loading would probably also occur but methods were not available to access the degree of possible reduction. The degree of reduction in runoff quantity decreases with increasing precipitation intensity such that essentially no reduction in runoff volume would occur during a major precipitation event.

7.2. Recommendations.

a. Needs for Additional Studies. The findings of this study indicate that the identification and quantification of the causal factors of measured urban runoff pollution must go beyond the bounds of streets. It is important that additional funds and efforts be directed toward a full understanding of the sources and nature of the urban runoff pollution phenomena. Otherwise, future management studies will continue to be relegated to the same analysis method of using an average runoff concentration. With the estimated cost of physical urban runoff pollution control facilities expected to reach phenomenal figures, an understanding of the origin and removal of urban pollutants is necessary. Efforts were made in this study to evaluate the runoff pollution contribution from sources other than streets.

However, much of the data used in this analysis was synthesized. Comprehensive study efforts are needed to:

1. Identify the major sources of urban runoff pollutants;

2. Quantify the role of each source;

3. Describe accumulation or origin processes for pollutants at each source;

4. Describe precipitation removal processes for pollutants at each source;

5. Describe any interactive relationship between sources, e.g., streets, a source of dust for other areas;

6. Describe applicability of each source to non-structural management control; and

7. Define planning, regulatory, or maintenance requirements necessary to reduce runoff pollution to acceptable levels.

b. Changes Needed for STORM. The water quality subroutine in STORM cannot be considered a viable routine at the present time for use in predicting runoff quality for management studies. Artificial adjustment of the accumulation rate and pollutant "strength" input values above levels that have been measured on streets would appear to be only a superfluous attempt to match predicted and measured runoff quality values without having a physical basis. The major inherent problem in the model simulation is that streets are apparently not a major source of the runoff pollution load. Thus, the first concern is the identification, quantification, and modeling

of the contribution of pollutants originating from other sources. These changes will be contingent upon the research findings discussed previously. Other changes may be needed in the future to further refine the subroutine for collection and washoff of debris from the streets. Care must be exercised in any refinement to maintain the time continuous element in the model. Major categorical changes that are needed are discussed in the succeeding comments. The actual need for the further refinements will probably not be fully realized until additional pollution sources have been identified and included in the water quality subroutine.

1. Accumulation rate. This study demonstrates that the accumulation of debris on the street was not linear over the period of data acquisition in this study. A variety of averaging techniques can be used to derive the "best" linear approximation of long-term results. The techniques discussed in this report utilized an average computed historical runoff event to determine the average loading of debris on the street for various frequencies of street sweeping. The use of an average value may be adequate for long-term analyses but may not be adequate when evaluating specific historical precipitation events. At a minimum, it is believed that at least some seasonal adjustment for accumulation rate should be incorporated in the model.

2. Pollutant "strength." The type and pollutional quality of debris also changes during the year. As the model is refined and more data becomes available, seasonal adjustments may be needed for

these input values also. The data collected in this study did not indicate any major differences in pollutant "strength" for the various types and ages of residential areas sampled through much of the summer. Study findings also indicate that the pollutant "strength" of the suspended and settleable debris fractions should be changed to input variables rather than constants in the model.

3. Street density. The importance of the "street density" factor in the program computations must also be questioned. Pollution loads as determined by the model are very sensitive to input values for this parameter. Other physical factors in an urban area, such as those listed in Table 2, may have greater significance when defining the rate of debris accumulation for a given area. It was determined quite definitely that the amount of debris accumulating in an area was directly proportional to the developmental age of the urban area. Again, the importance of describing each factor is relative to the eventual refined state of the model.

4. Availability factor. Additional consideration should be given to the meaning and purpose of the availability factor in the model. It was assumed in this report that this factor more realistically describes particulate transport phenomena. If so, applicable descriptive runoff-particulate transport factors for various size fractions should be investigated and evaluated. Such factors would have greater physical significance and be more quantifiable than the terms "suspended" and "settleable." In addition, the sensitivity of

any derived factors to various physical parameters such as slope and type of street surfacing should be evaluated to determine whether or not such factors should be input values rather than constants in the model.

5. Additional capability. The time continuous computational element of the model offers great potential and versatility to management and assessment type of studies. Additional versatility for adaptive uses of the model should be investigated. Two possibilities were evaluated on a first cut basis in this report. These were 1) evaluation and optimization of a street sweeper program and 2) management of interior drainage by diverting impervious runoff across pervious areas. The full potential for this model element should be investigated for applications in water resource management.

SECTION VIII

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APPENDIX A

SUMMARY OF LABORATORY ANALYSIS
OF STREET DEBRIS SAMPLES

CITY OF OMAHA STREET SWEEPING STUDY, JUNE, SEPTEMBER 1974

SIZE DISTRIBUTION OF STREET DEBRIS COLLECTED BY HAND SWEEPING

		Percent of Total Retained on U.S. Standard Sieve															
		No. 4		No. 10		% Passing 10	No. 20		No. 70		No. 140		No. 270		Passing 270	
Sector	Date Collected	Fixed	Vol.	Fixed	Vol.		Fixed	Vol.	Fixed	Vol.	Fixed	Vol.	Fixed	Vol.	Fixed	Vol.
CC-8	7/24	2.0	8.8	4.2	2.1	82.9	5.3	4.5	29.6	2.6	18.6	1.2	9.2	1.1	9.9	0.9
CC-8	8/23	9.3	4.2	13.3	2.0	71.2	13.6	1.[illegible]	27.5	2.4	9.0	1.0	4.6	0.6	10.1	0.8
CC-8	9/6	5.6	3.2	6.4	1.6	83.4	7.8	1.[illegible]	21.9	2.5	12.2	2.2	8.1	1.5	23.4	2.2
SD-4	8/23	3.7	10.8	6.8	8.4	70.3	12.1	6.[illegible]	27.1	6.6	10.0	0.9	3.7	0.4	3.2	0.2
SD-4	8/23	15.1	5.6	9.7	4.0	65.6	10.7	4.[illegible]	23.8	2.9	10.4	1.1	4.8	0.5	6.5	0.5
SD-4	9/5	2.1	4.0	4.0	3.0	86.9	6.2	3.[illegible]	31.2	3.5	17.2	1.4	7.8	0.8	14.6	1.1
BD-6	7/24	18.9	23.3	7.9	7.0	42.9	6.4	3.[illegible]	14.0	3.3	5.3	1.0	3.3	0.4	5.5	0.3
BD-6	8/30	7.1	8.8	9.2	5.7	69.2	10.5	4.[illegible]	25.6	5.1	12.6	1.4	4.6	0.7	3.9	0.4
BD-6	9/6	1.8	3.2	9.2	0.6	85.2	13.7	1.[illegible]	33.0	1.8	14.2	0.9	6.7	0.5	12.1	0.7
WB-7	8/8	10.0	0.4	15.4	0.3	64.9	14.9	0.[illegible]	20.2	0.9	6.7	0.3	5.0	0.4	15.1	1.0
WB-7	8/23	4.8	29.2	5.9	12.3	47.8	5.5	9.[illegible]	17.0	3.4	6.4	0.8	2.1	0.3	2.6	0.1
WB-7	8/23	8.0	0.4	9.6	0.5	81.5	14.5	0.6	25.5	1.2	6.9	0.4	5.9	0.3	25.1	1.0
WB-7	9/6	7.2	0.4	5.8	1.1	85.5	14.3	2.1	45.3	3.7	10.9	0.8	3.6	0.4	4.2	0.2
NB-1	7/26	16.4	0.9	5.4	1.4	75.9	8.3	4.[illegible]	29.1	3.0	11.1	0.9	5.5	0.5	12.4	0.5
NB-1	8/30	8.2	6.8	9.8	13.4	61.8	13.2	12.[illegible]	22.2	3.9	5.9	0.7	1.8	0.2	1.8	0.1
NB-1	9/6	11.6	2.4	22.3	1.5	62.2	21.7	2.[illegible]	27.0	1.7	5.5	0.5	1.6	0.2	1.5	0.2
BA-1	8/30	1.8	0.4	1.6	1.4	94.8	4.6	2.[illegible]	53.5	0.8	9.6	0.2	3.5	0.2	19.2	0.6
BA-1	9/6	13.8	1.1	8.7	0.3	76.1	15.5	0.[illegible]	21.3	0.3	6.9	0.3	5.5	0.2	25.2	0.7
MB-2	8/30	8.2	0.0	7.8	0.2	83.8	5.9	1.[illegible]	25.9	1.5	12.5	0.8	9.5	0.5	24.8	1.0
MB-2	9/5	15.7	11.9	5.8	10.6	56.0	9.2	9.[illegible]	21.0	6.5	5.5	0.4	1.8	0.2	2.0	0.1
MC-2	8/8	8.0	4.1	14.8	4.4	68.7	21.1	4.[illegible]	28.4	5.2	4.7	0.8	1.6	0.3	2.0	0.1
MC-2	8/30	3.5	0.3	7.1	0.4	88.7	14.4	0.[illegible]	32.8	1.1	10.7	0.6	5.7	0.5	21.2	0.9
MC-2	9/5	21.1	0.3	18.4	0.5	59.7	17.9	0.[illegible]	29.2	0.9	6.3	0.3	1.7	0.2	2.4	0.1

CITY OF OMAHA STREET SWEEPING STUDY, JUNE, SEPTEMBER 1974

SIZE DISTRIBUTION OF STREET DEBRIS COLLECTED BY MECHANICAL STREET SWEEPER

		Percent of Total Retained on U. S. Standard Sieve															
	Date	No. 4		No. 10		% Pass-	No. 20		No. 70		No. 140		No. 270		Passing 270	
Sector	Collected	Fixed	Vol.	Fixed	Vol.	ing 10	Fixed	Vol.	Fixed	Vol.	Fixed	Vol.	Fixed	Vol.	Fixed	Vol.
CC-8	7/24	7.2	1.9	10.8	2.5	77.6	16.4	1.5	40.3	3.3	8.1	0.9	2.5	0.4	2.8	0.3
CC-8	8/7	13.4	14.6	10.8	4.0	52.2	11.2	4.2	22.7	3.8	5.9	0.7	1.8	0.2	1.5	0.2
SD-4	8/5	23.4	8.1	28.3	7.0	33.2	14.1	2.3	11.1	1.6	1.7	0.3	0.7	0.1	1.1	0.2
SD-4	8/23	16.6	2.9	24.0	1.6	54.9	18.8	0.3	23.9	1.1	4.1	0.4	1.5	0.2	3.9	0.3
SD-4	9/5	5.3	3.1	11.7	3.7	76.2	17.7	2.7	36.5	3.0	8.6	0.6	2.9	0.3	3.6	0.3
BD-6	7/25	8.6	15.9	10.2	9.3	66.0	16.7	4.1	24.1	3.0	3.7	0.6	1.4	0.3	2.0	0.2
BD-6	8/12	15.7	15.7	17.7	5.0	45.9	16.4	2.2	19.2	2.2	3.1	0.3	1.0	0.1	1.2	0.1
WB-7	8/21	14.5	4.6	23.3	1.0	56.6	20.5	1.2	20.6	1.4	3.6	0.4	2.4	0.2	6.9	0.4
WB-7	9/4	19.3	1.7	19.1	1.0	58.9	19.6	1.2	26.6	1.1	4.5	0.2	1.8	0.1	3.7	0.2
NB-1	7/26	24.7	3.3	18.6	2.3	51.1	18.9	1.1	23.9	0.9	2.6	0.2	1.1	0.1	2.1	0.2
NB-1	8/14	15.8	0.7	21.4	0.9	61.2	21.8	0.9	29.6	1.4	4.3	0.2	1.2	0.1	1.7	0.1
NB-1	8/29	11.0	6.2	24.4	3.0	55.4	22.3	1.1	23.7	1.3	3.3	0.2	1.3	0.1	1.9	0.1
BA-1	7/29	13.2	9.8	25.8	3.0	48.2	20.6	1.6	17.9	1.4	2.1	0.2	1.2	0.1	2.8	0.2
BA-1	8/30	9.6	15.9	17.0	2.4	62.2	18.6	2.3	23.3	2.7	3.5	0.4	1.9	0.2	2.1	0.1
MD-2	8/27	31.0	11.1	20.8	1.8	35.3	16.9	1.8	12.0	1.0	1.0	0.1	0.4	0.1	1.0	0.1
MD-2	9/6	12.5	0.4	15.7	0.6	70.8	23.1	0.9	37.1	1.1	3.5	0.1	1.3	0.1	3.4	0.1
MC-2	8/22	32.9	6.8	24.9	2.0	33.4	16.5	1.1	11.2	0.7	1.3	0.1	0.7	0.1	1.6	0.1
BB-1	7/30	19.6	1.9	26.9	0.8	50.8	24.0	0.6	20.1	0.7	1.9	0.1	0.9	0.1	2.3	0.1
BB-1	8/19	18.0	1.0	21.4	0.5	59.1	17.2	0.3	26.8	0.6	5.2	0.3	2.5	0.2	5.7.	0.3
Center St.	8/26	5.5	0.8	13.2	0.8	79.7	21.2	0.6	47.3	1.2	6.9	0.2	1.0	0.1	1.2	0.0

CITY OF OMAHA STREET SWEEPING STUDY, JUNE, SEPTEMBER 1974

QUALITY OF "HAND-SWEEPING" STREET DEBRIS SAMPLES

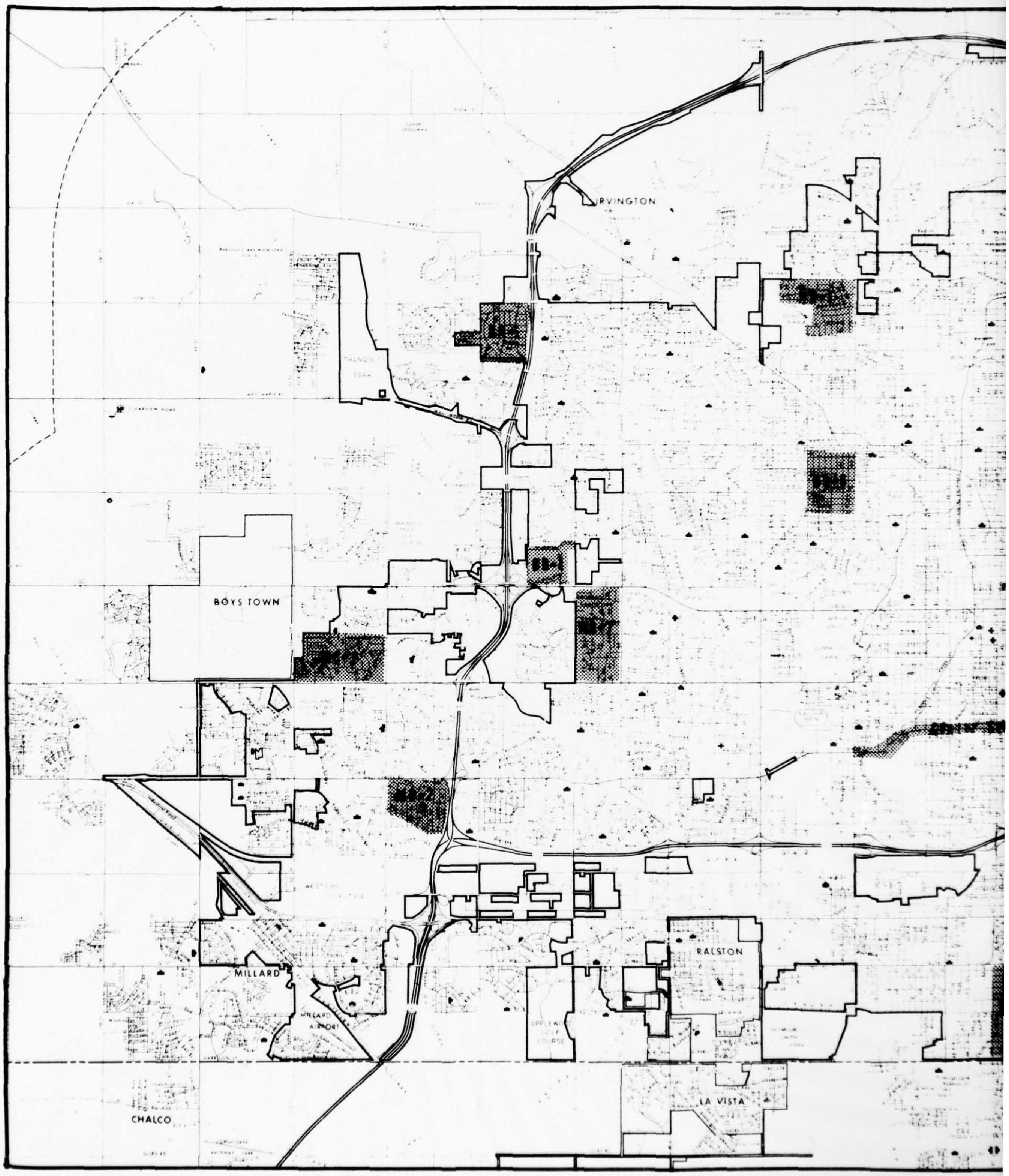
Sector	Date Collected	Lab Prep Method[1/]	% Passing 10	SS	VSS	BOD$_5$	COD	Ext. PO$_4$ X10	Tot N X10	Total Coli Count[2/] X10	Zn X10	Pb X10	Ni X10	Hg X10	Cr X10
			Grams Per 100 Grams Passing U. S. Standard No. 10 Sieve												
CC-8	7/24	A	82.9	0.68	0.28	0.11	0.36	9.0	8.4	0.27	4.7	23.1	0.8	15.0	3.3
		B		16.2	2.92	1.21	3.57	65.0	57.0		51.5	181.5	2.5	*	21.8
CC-8	8/23	A	71.2	0.94	0.25	0.12	0.30	6.0	9.0		5.3	13.2	0.4	17.8	2.9
		B		20.8	3.03	0.45	3.55	62.0	46.0	0.83	67.4	148.0	3.1	*	24.2
CC-8	9/6	A	83.4	0.76	0.22	0.17	0.49	11.5	8.9		9.3	14.0	0.3	0.4	3.3
		B		32.6	5.47	1.83	8.20	130.0	122.0	15.0	154.0	249.3	5.6	*	40.9
SD-4	8/23	A	65.6	0.68	0.28	0.28	0.36	11.5	16.7		2.6	4.1	0.3	17.6	1.5
		B		19.2	3.21	0.70	4.13	70.0	84.0	3.75	34.1	57.4	2.9	*	21.0
SD-4	8/23	A	70.3	1.80	1.05	1.03	1.26	11.5	38.6		6.4	14.5	0.5	4.5	3.3
		B		9.6	2.63	1.14	3.62	68.0	94.0	1.24	29.3	61.4	1.7	*	15.2
SD-4	9/5	A	86.9	0.70	0.33	0.23	0.37	11.0	10.6		3.7	7.7	0.3	2.2	0.7
		B		16.2	2.06	0.64	3.53	55.0	51.0	6.66	46.2	107.1	2.8	*	21.2
BD-6	7/24	A	42.9	1.76	0.81	0.38	1.09	23.5	35.3		4.2	8.7	1.1	7.9	3.9
		B		35.0	5.76	1.92	6.50	149.0	195.0	14.9	49.3	94.1	5.8	*	54.2
BD-6	8/30	A	69.2	0.90	0.38	0.19	0.21	14.5	11.8		4.2	10.5	0.3	0.4	2.4
		B		9.5	2.51	0.84	2.94	46.0	70.0	6.1	29.7	62.6	1.4	*	15.4
BD-6	9/6	A	85.2	0.62	0.24	0.14	0.27	8.5	12.3		11.4	8.1	0.3	0.2	0.7
		B		14.8	1.96	0.56	2.35	49.0	44.0	0.67	11.5	84.0	2.5	*	16.7
WB-7	8/8	A	64.9	1.99	0.36	0.08	0.22	13.5	6.4		3.8	9.2	1.4	1.7	6.7
		B		41.5	3.56	0.30	1.22	92.0	26.0	0.01	36.8	50.0	6.3	*	47.4
WB-7	8/23	A	47.8	1.71	0.95	0.90	1.25	30.0	34.8		3.9	5.5	0.7	7.8	3.0
		B		9.08	3.30	1.65	6.80	104.0	97.0	26.1	22.1	29.1	1.9	*	24.5
[illegible]	[illegible]	A	[illegible]	2.72	[illegible]	0.07	0.16	4.0	5.6		4.1	1.5	1.3	0.1	11.4
		B		88.1	[illegible]	0.29	1.88	184.0	43.0	0.04	27.4	8.4	[illegible]	*	[illegible]
WB-7	9/6	A	85.5	0.90	0.25	0.18	0.45	1.4	1.0		4.2	31.2	0.3	0.6	3.0
		B		10.0	2.00	1.53	1.80	39.0	43.0	24.8	19.1	71.3	0.9	*	13.1
NB-1	7/26	A	75.9	1.61	0.59	0.29	0.88	21.0	19.8		10.3	25.2	1.1	390.0	5.2
		B		10.1	2.09	0.79	2.76	79.0	49.0	0.44	35.7	74.7	2.4	*	20.2
NB-1	8/30	A	61.8	1.10	0.56	0.49	0.39	27.0	15.4		3.8	8.5	0.5	41.6	2.6
		B		5.0	2.39	1.10	3.17	103.0	90.0	9.4	13.4	41.7	0.9	*	8.9
NB-1	9/6	A	62.2	0.29	0.09	0.11	0.19	5.0	12.8		4.5	9.5	0.2	0.6	0.3
		B		2.8	0.56	0.50	0.60	14.0	23.5	2.2	48.4	38.3	0.3	*	4.0
BA-1	8/30	A	94.8	0.89	0.14	0.06	0.10	5.0	3.8		2.3	2.7	0.5	0.0	3.3
		B		24.5	1.37	0.42	0.56	49.0	16.6	0.70	11.7	7.6	4.2	*	21.6
BA-1	9/6	A	76.1	1.06	0.18	0.05	0.07	9.0	3.4		4.5	0.9	0.4	0.2	3.3
		B		35.9	2.09	0.58	0.89	71.0	26.5	0.12	29.0	50.8	5.1	*	34.7
MB-2	8/30	A	83.8	0.98	0.22	0.06	0.12	5.5	7.1		3.0	3.9	0.4	0.0	3.0
		B		45.0	2.97	0.45	1.45	110.0	35.0	2.80	33.0	37.4	6.3	*	45.1
MB-2	9/5	A	56.0	3.2	1.64	1.75	1.85	61.0	54.0		9.3	15.6	0.9	0.0	7.9
		B[3/]		-	-	-	-	-	-	712.5	-	-	-	-	-
MC-2	8/8	A	68.7	1.22	0.66	0.38	0.90	33.0	33.0		6.5	37.3	1.6	15.6	2.0
		B[3/]		-	-	-	-	-	-	0.35	-	-	-	-	-
MC-2	8/30	A	88.7	1.16	0.22	0.13	0.19	9.5	3.3		4.9	10.6	0.4	0.4	3.3
		B		21.4	1.39	0.39	0.99	45.0	31.0	0.44	24.9	49.8	3.4	*	26.9
MC-2	9/5	A	59.7	0.78	0.30	0.19	0.25	26.5	192.0		3.6	26.2	0.3	0.0	2.6
		B		7.96	1.04	0.40	0.84	80.0	144.0	19.3	23.3	87.5	1.7	*	14.9

*Only minor quantities of mercury detected during laboratory analysis of preparation method B. Several days separated the two analyses. It is suspected that the mercury in the sample volatilized during this period.

1/Preparation method A - determination of suspended solids level of street pollution. Preparation method B - determination of suspended plus settleable solids level of street pollution.

2/Total Coliforms were measured on the total sample. Value reported is laboratory count divided by fraction passing No. 10 sieve.

3/Not sufficient sample to make second determination.



Study Sectors

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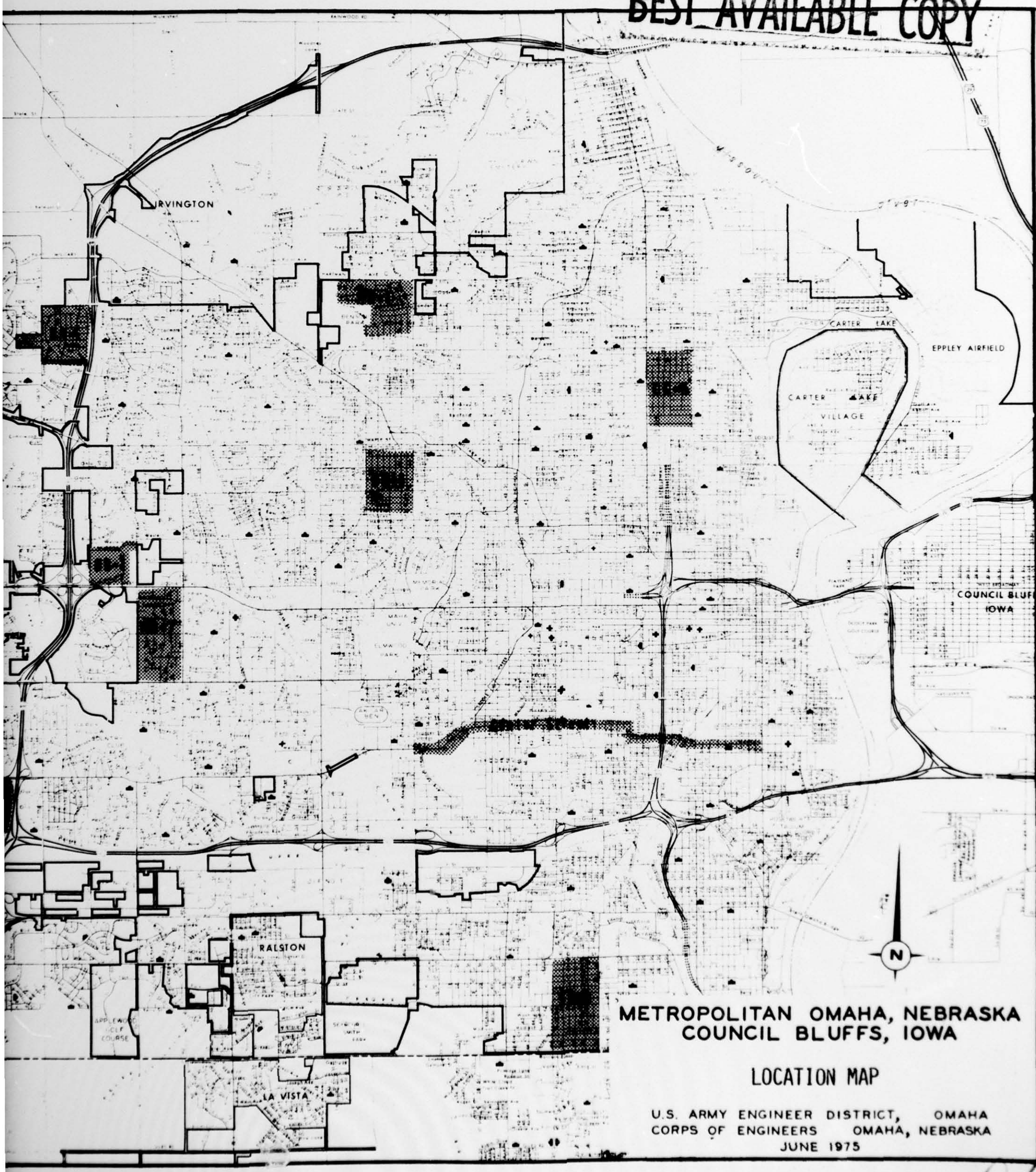

Study Sectors

VOLUME V ANNEX D PLATE 1

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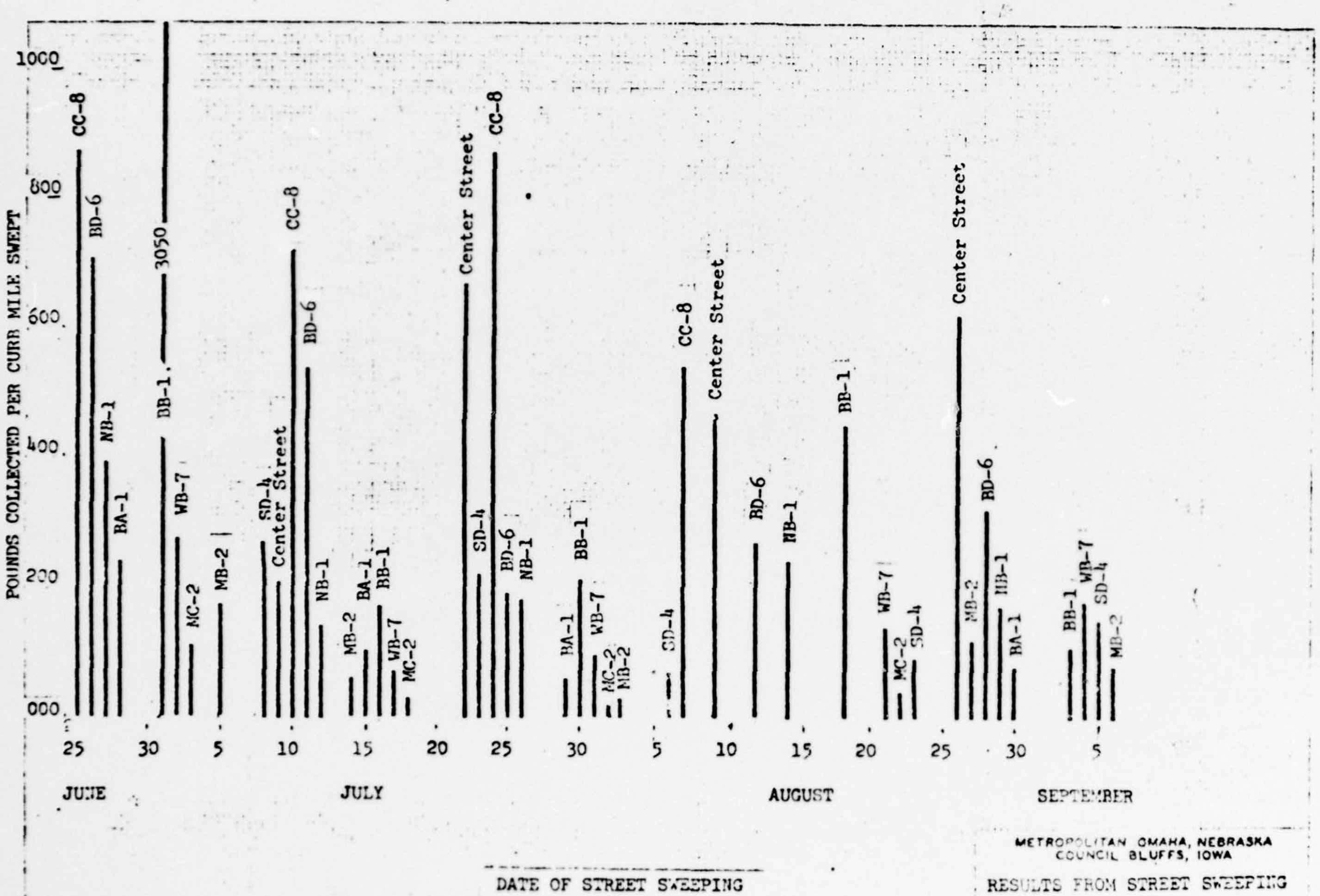

METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

RESULTS FROM STREET SWEEPING

U.S. ARMY ENGINEER DISTRICT, OMAHA
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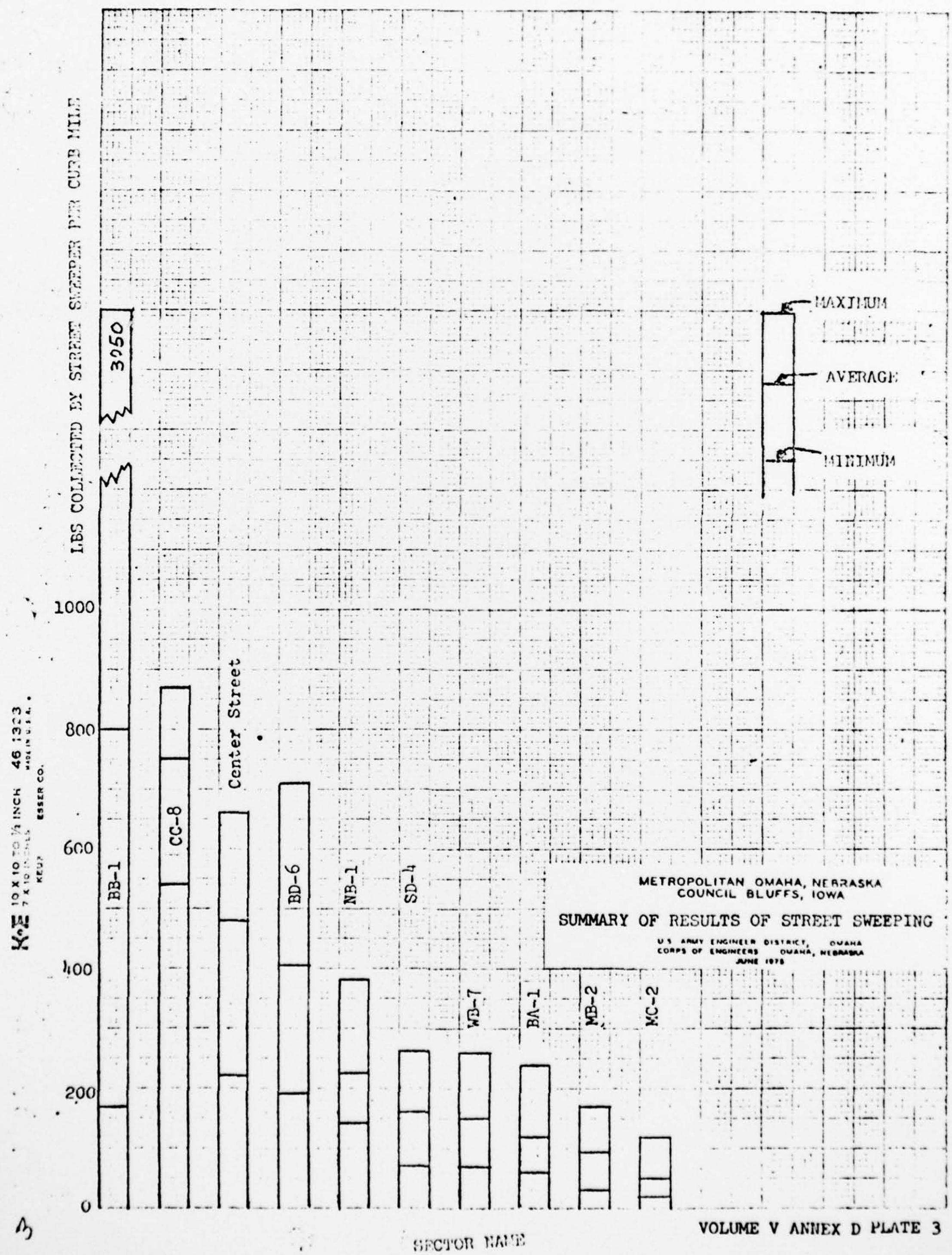
JUNE 1975

VOLUME V ANNEX D PLATE 2



METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

SUMMARY OF RESULTS OF STREET SWEEPING

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

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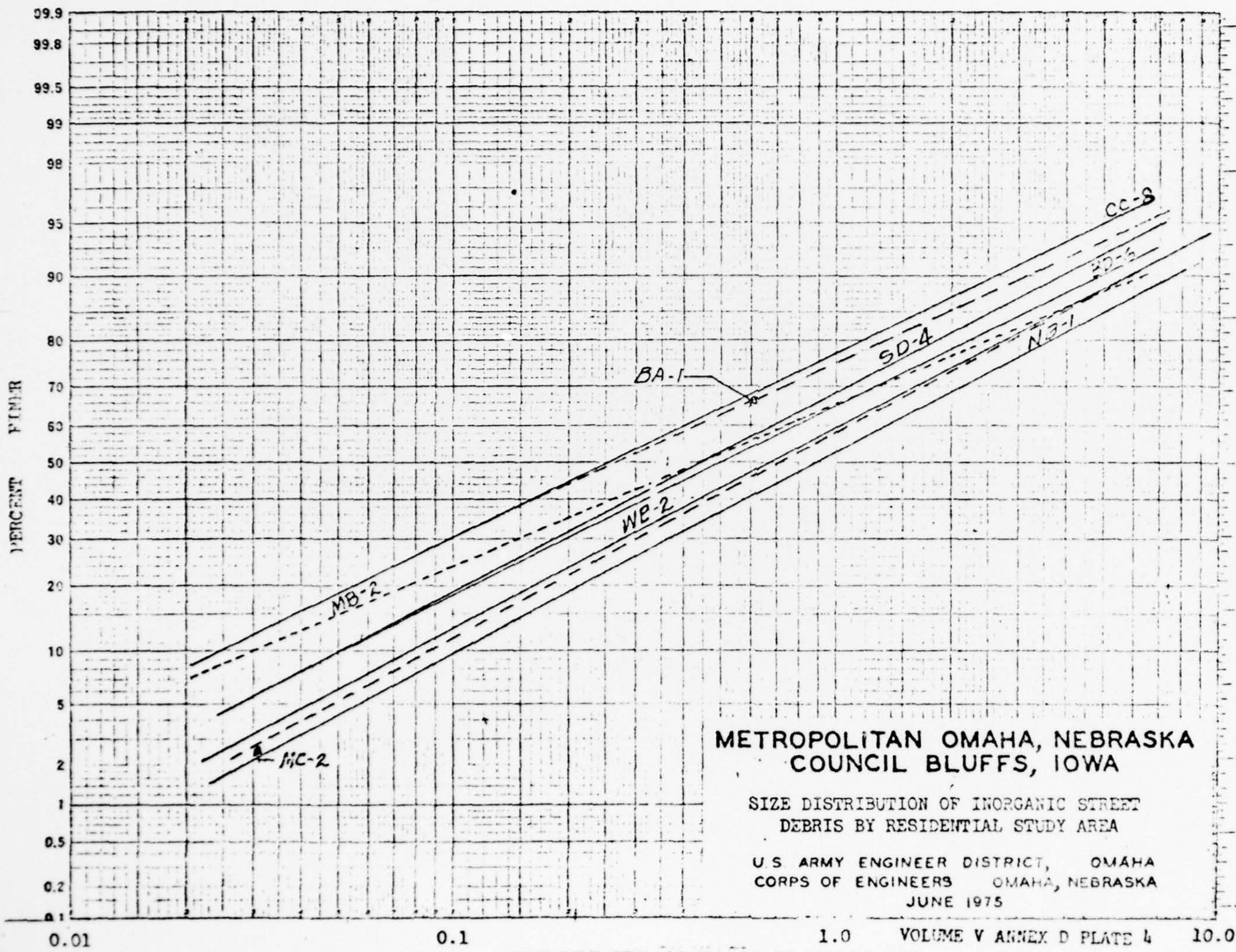

METROPOLITAN OMAHA, NEBRASKA COUNCIL BLUFFS, IOWA

SIZE DISTRIBUTION OF INORGANIC STREET DEBRIS BY RESIDENTIAL STUDY AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

VOLUME V ANNEX D PLATE 4

PARTICLE SIZE OF DEBRIS IN MILLIMETERS

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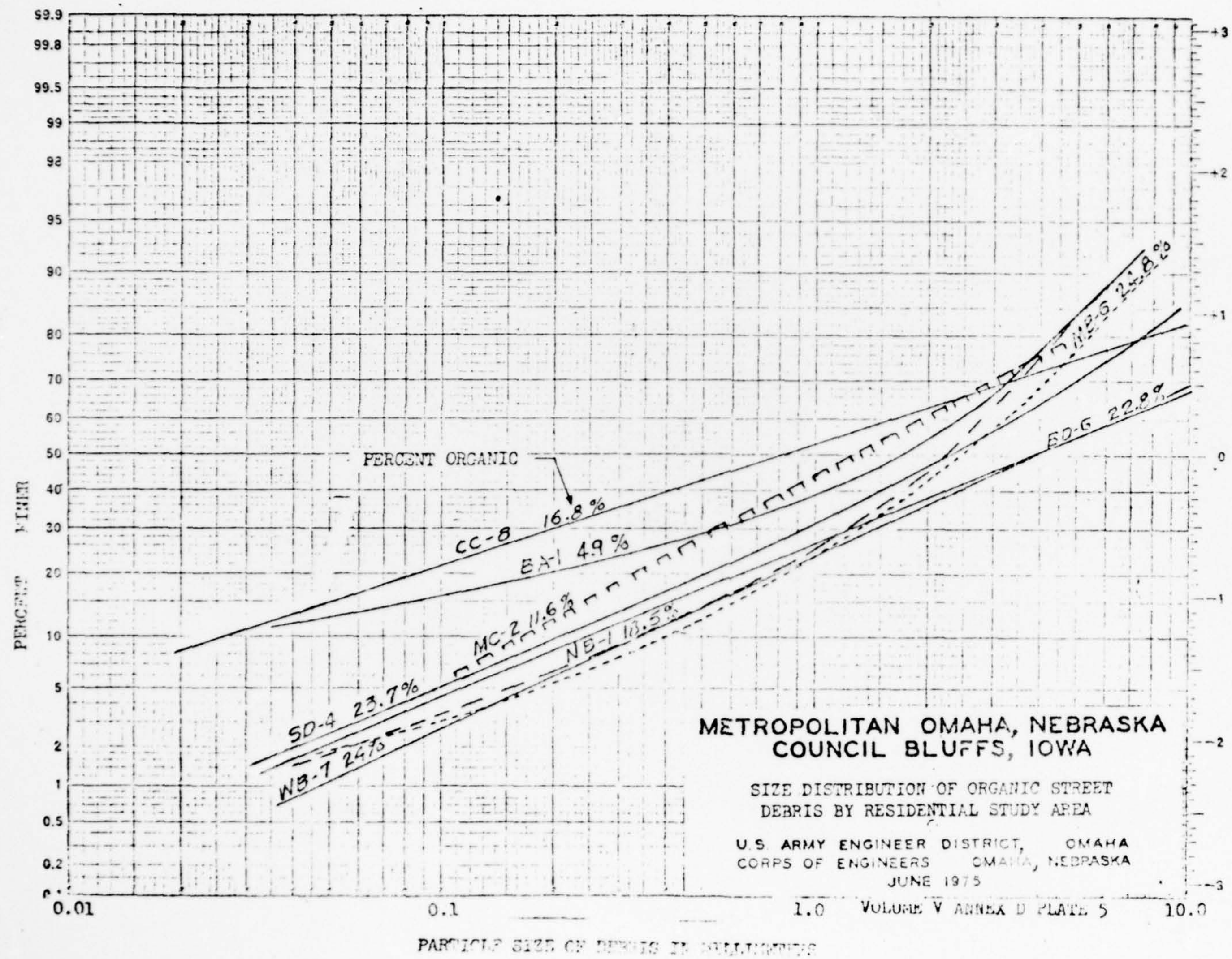

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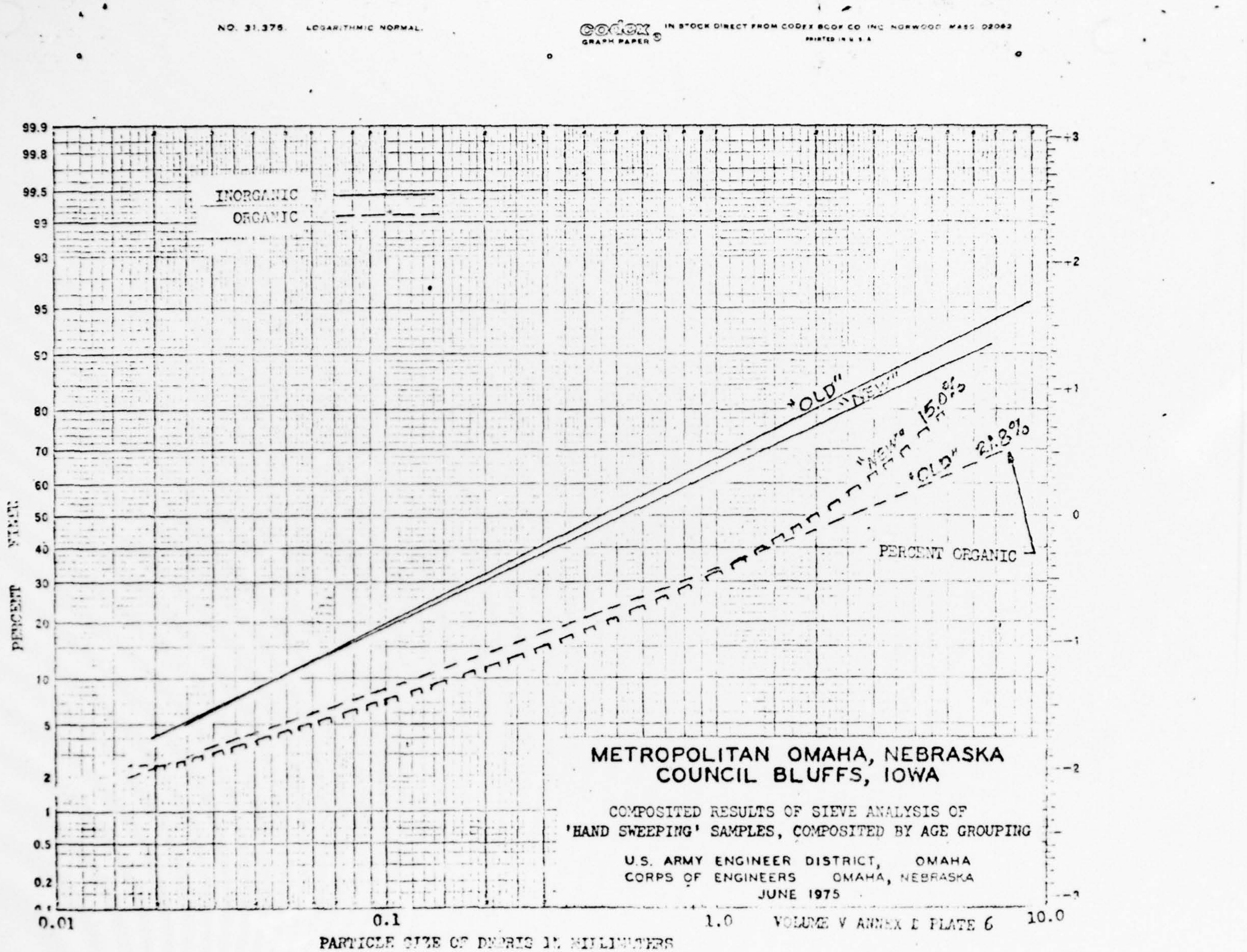
COUNCIL BLUFFS, IOWA

SIZE DISTRIBUTION OF ORGANIC STREET DEBRIS BY RESIDENTIAL STUDY AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

VOLUME V ANNEX D PLATE 5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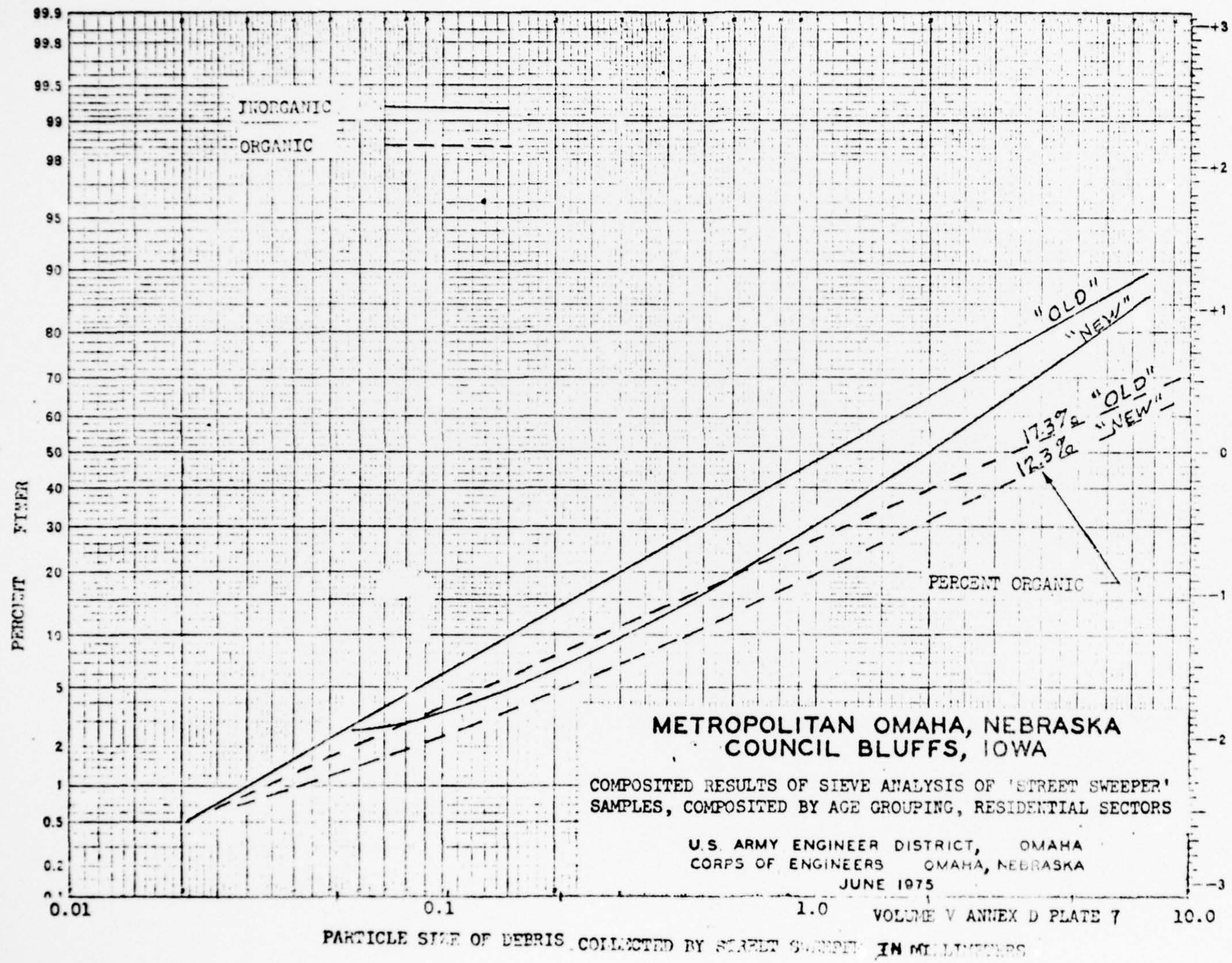
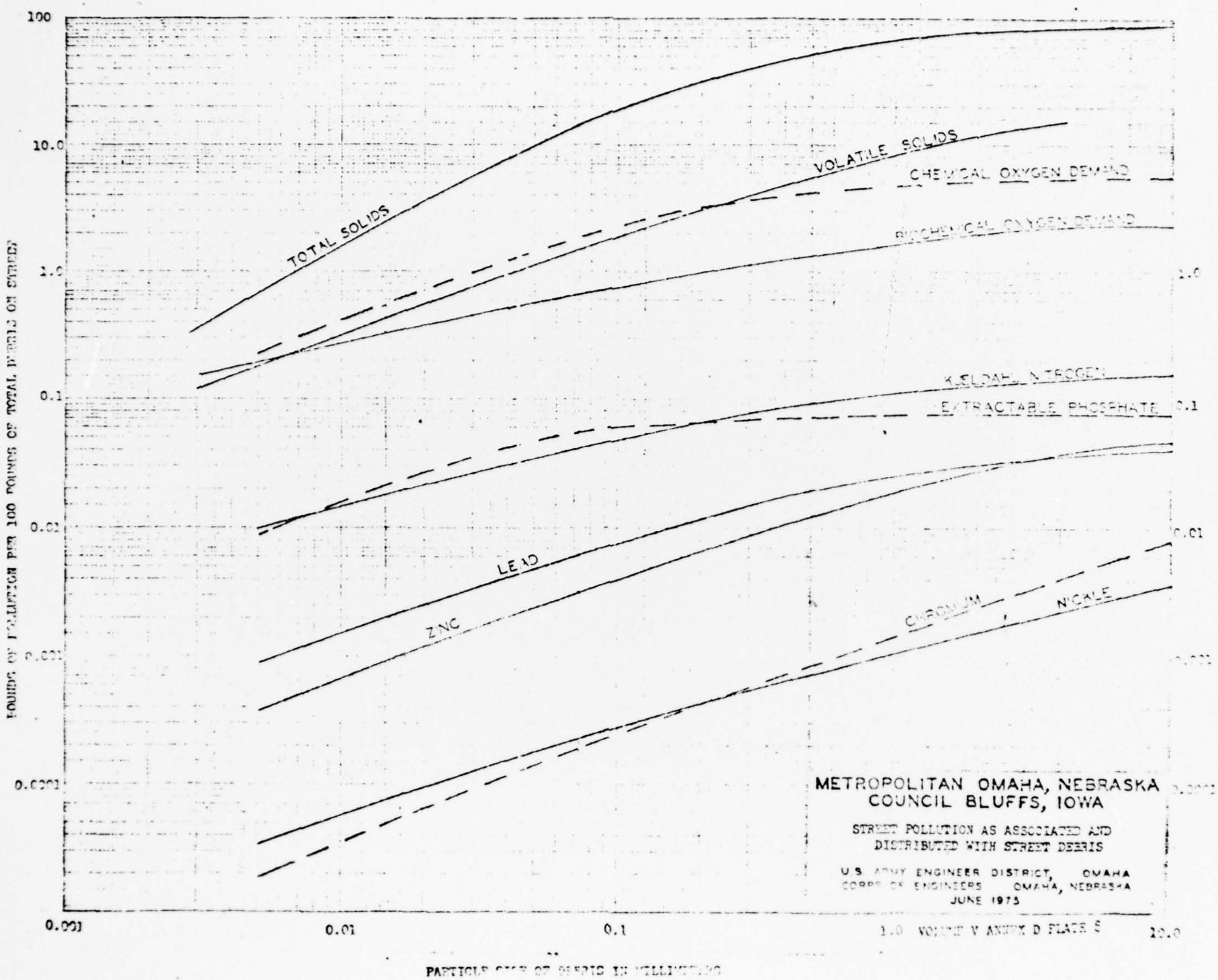
"NEW"
"NEW" 15.0%
"OLD" 21.8%
PERCENT ORGANIC
PERCENT FINER
PARTICLE SIZE OF DEBRIS IN MILLIMETERS
METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA
COMPOSITED RESULTS OF SIEVE ANALYSIS OF
'HAND SWEEPING' SAMPLES, COMPOSITED BY AGE GROUPING
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975
VOLUME V ANNEX D PLATE 6



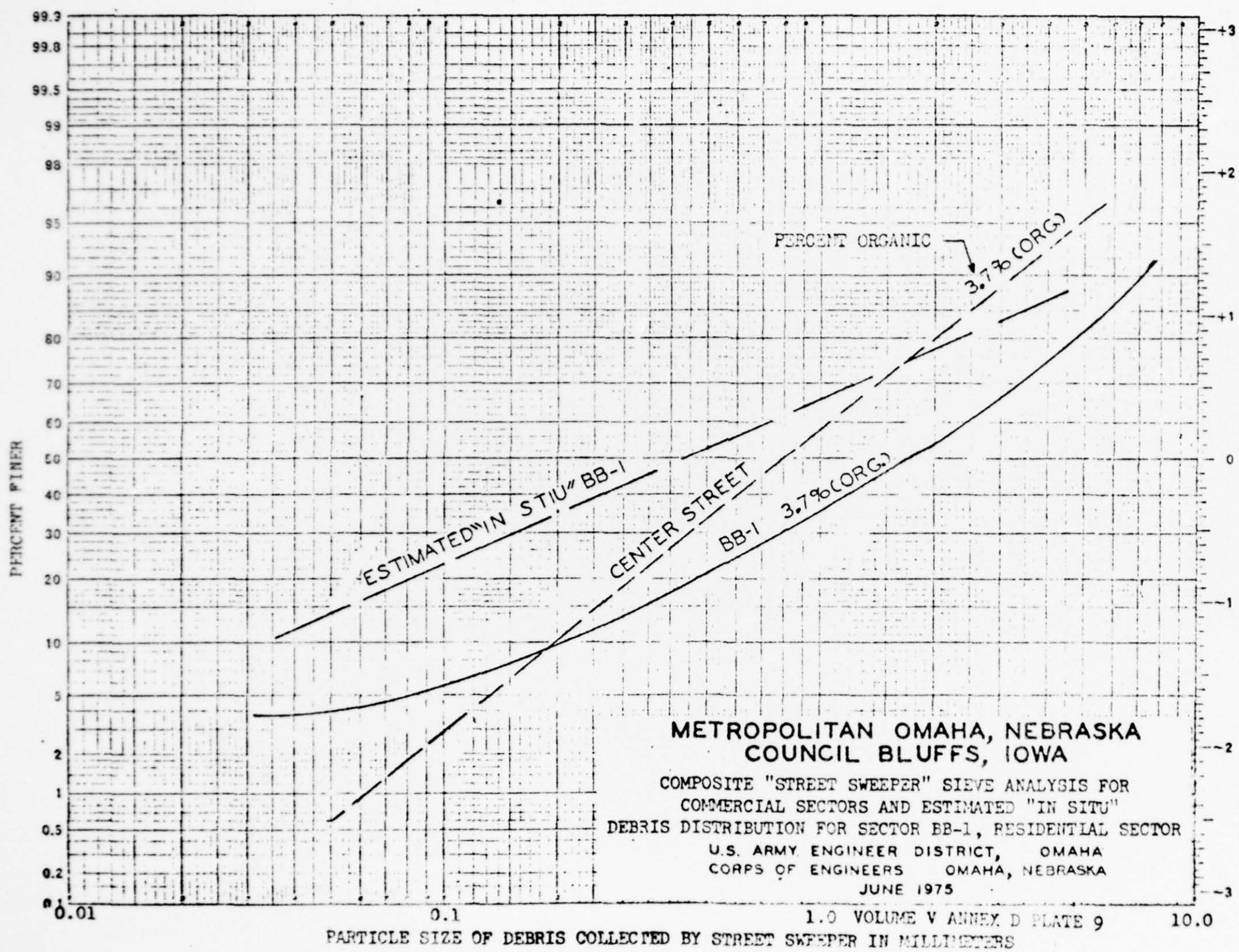
METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPOSITED RESULTS OF SIEVE ANALYSIS OF 'STREET SWEEPER' SAMPLES, COMPOSITED BY AGE GROUPING, RESIDENTIAL SECTORS

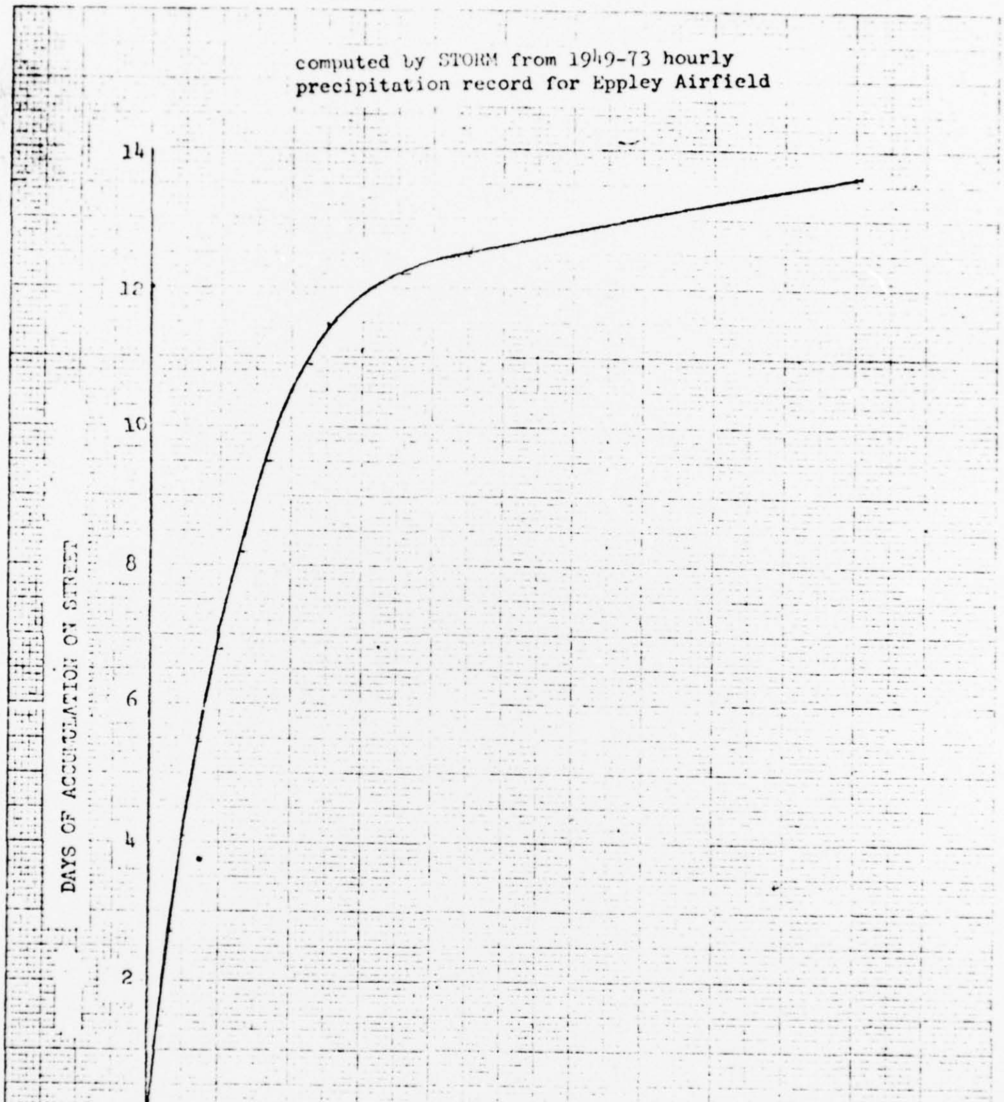
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975



VOLUME V ANNEX D PLATE 5



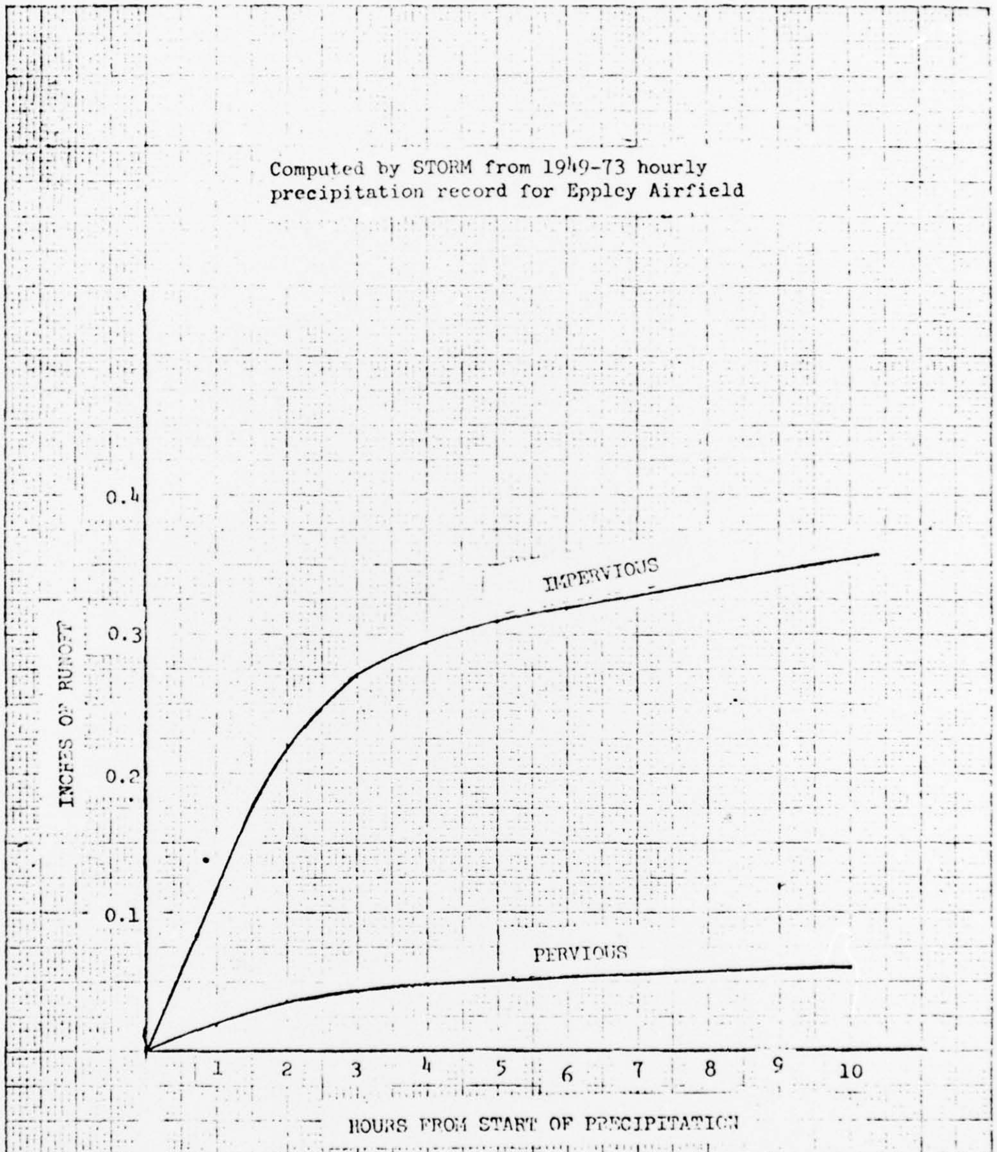
VOLUME V ANNEX D PLATE 9



METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPUTED AVERAGE ACCUMULATION OF DEBRIS ON STREET PRIOR TO PRECIPITATION FOR OMAHA, NEBR.

U S ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975



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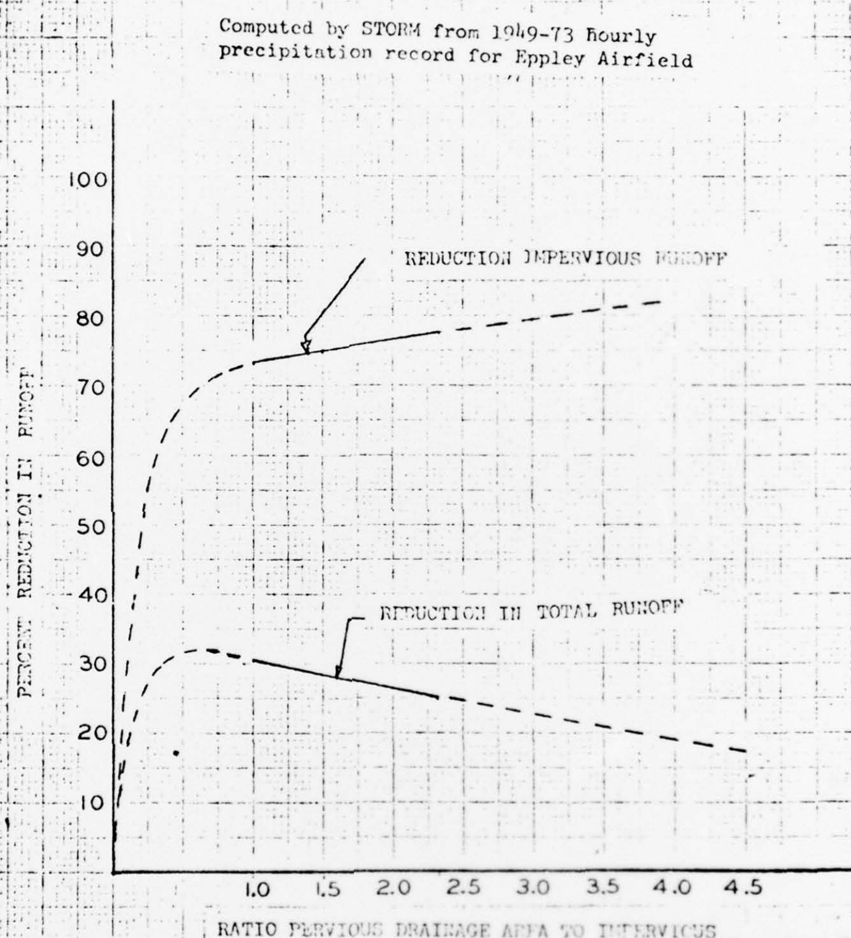
COUNCIL BLUFFS, IOWA

AVERAGE RUNOFF EVENT FOR OMAHA, NEBRASKA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

VOLUME V ANNEX D PLATE 11



Assumed saturated infiltration rate of 0.3 in/hr.

METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPUTED REDUCTION IN URBAN RUNOFF BY DRAINAGE OF IMPERVIOUS RUNOFF ACROSS PERVIOUS AREAS

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

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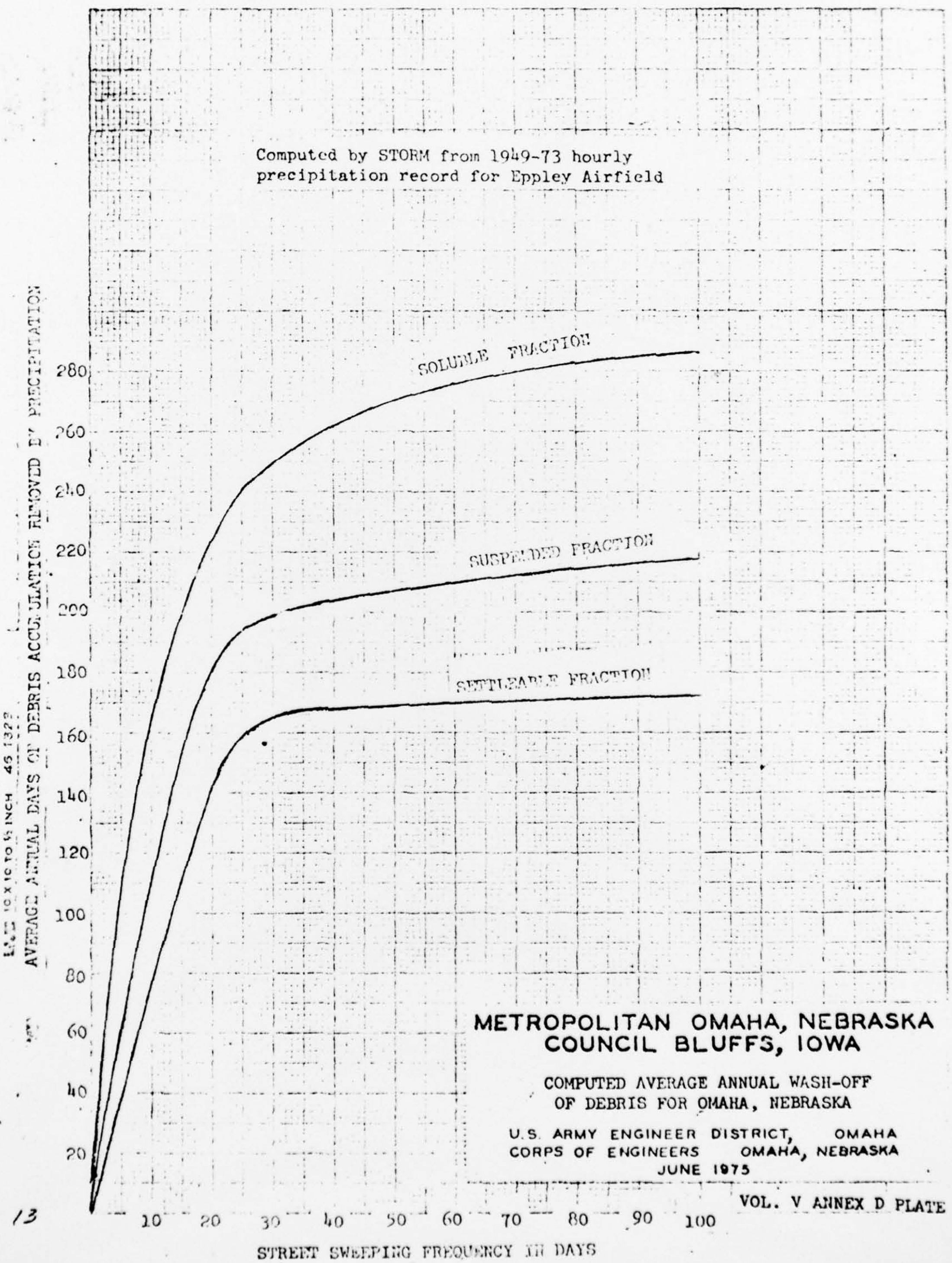

METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPUTED AVERAGE ANNUAL WASH-OFF OF DEBRIS FOR OMAHA, NEBRASKA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

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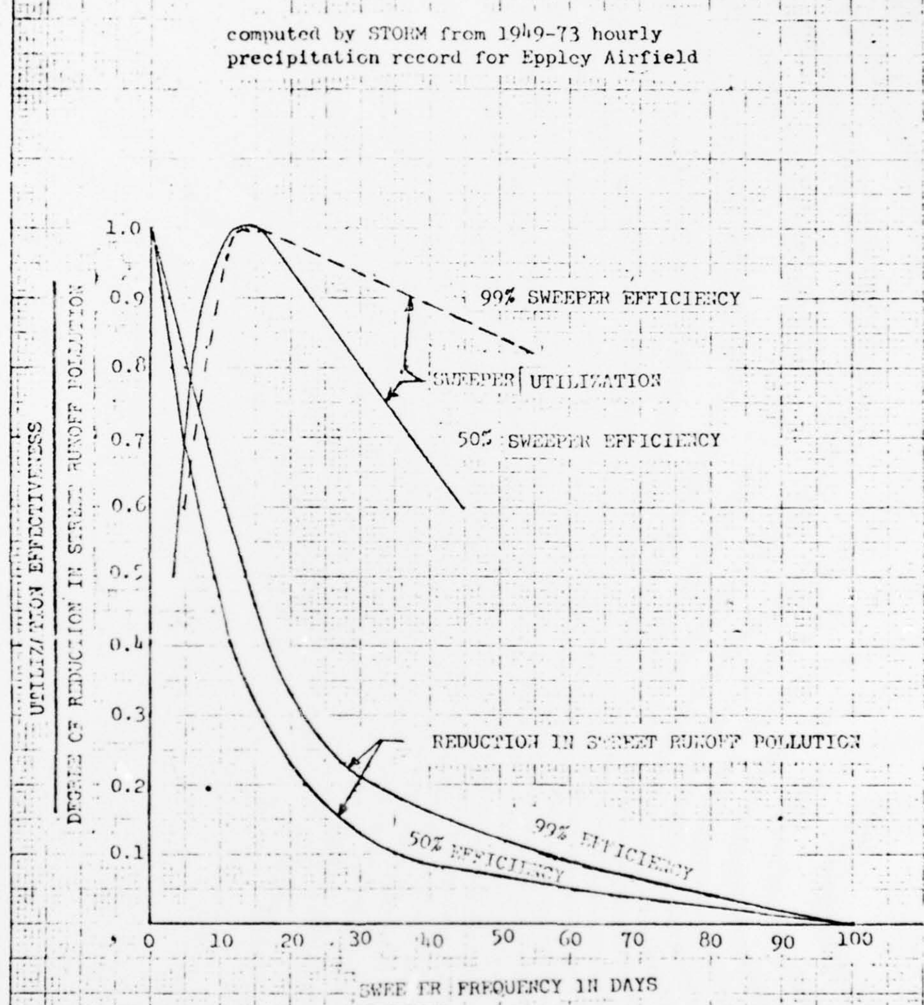

METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPUTED REDUCTION IN STREET
POLLUTION BY STREET SWEEPING

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

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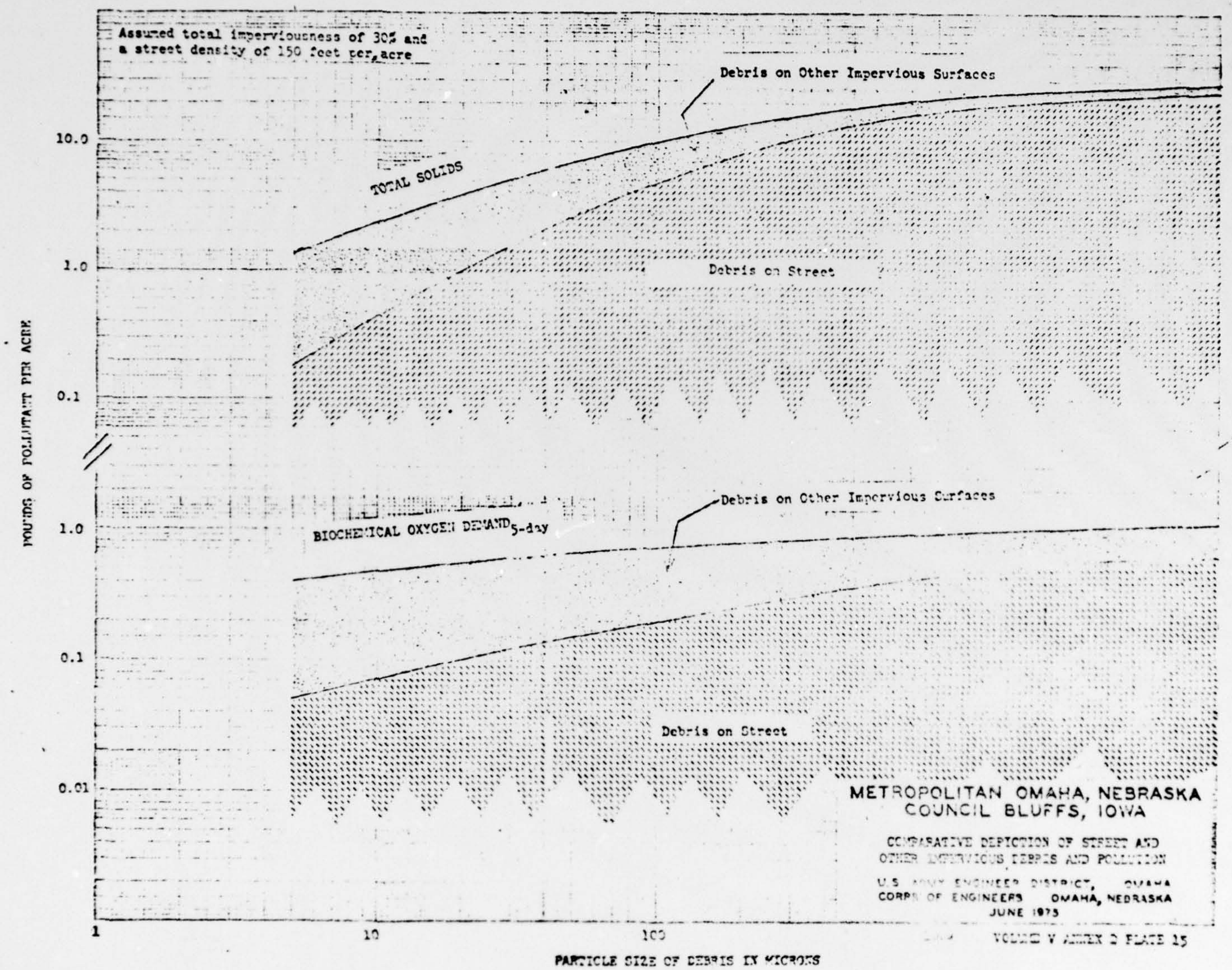

METROPOLITAN OMAHA, NEBRASKA
COUNCIL BLUFFS, IOWA

COMPARATIVE DEPICTION OF STREET AND OTHER IMPERVIOUS DEBRIS AND POLLUTION

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JUNE 1975

VOLUME V ANNEX D PLATE 15